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CONTRACT NUMBER FA-SS-67-03

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6 DOCUMENT NO D6A11786-5

TITLE: PRODUCTION SST PARAMETRIC ENGINE STUDIES-
MISSION ANALYSIS

MODEL 2707-300

ISSUE NO ______ TO: DDC DATE

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ABSTRACT

This document presents the results of a parametric engine cycle study which evaluates the effect of engine cycle on noise and performance of the Production SST. The engine cycles considered are duct burning turbofans, dry turbojets, and afterburning turbojets.

KEY WORD LIST

Parametric
Engine
Cycle
Noise
Performance
Production

TABLE OF CONTENTS

The purpose of this study was to evaluate the effect of engine cycle parameters on airport noise and airplane performance to determine whether a change in engine cycle from an afterburning turbojet should be considered for the production SST. This document is the fifth of a series of five documents prepared for this study. The other documents are:

D6A11[illegible]-1, SST Parametric Engine Library - Design

D6A11[illegible]-2, SST Parametric Engine Library - Installed Engine Performance

D6A11[illegible]-3, SST Parametric Engine Library - Acoustics

D6A11[illegible]-4, SST Parametric Engine Studies - Weights Analysis

The engine cycles that have been considered include selected duct burning turbofans, dry turbojets and afterburning turbojets. Each engine cycle was evaluated on the production airplane configuration with [illegible] passengers at a maximum taxi weight of [illegible] lbs. The mission analysis was based on the "Potential Production Technology" level (Ref. 1) which includes the effects of technology improvements in the areas of aerodynamics, structures, propulsion, together with reduced fuel reserves. Parametric studies were made to select the best engine for each engine cycle consistent with a maximum airport noise objective of 116.5 PNdB at 1500 ft. and a community noise objective of [illegible] EPNdB (Ref. 2). The 116.5 PNdB noise value was arbitrarily chosen because it was the best that could be achieved by the General Electric Company from tests on a [illegible] tube suppressor. The effect on engine size of using a simple [illegible] suppressor to meet the noise objective of 116.5 PNdB was also evaluated on each engine.

relative to the 633 lb/sec unsuppressed afterburning turbojet (side-line noise = 120 PNdb), the range losses to achieve 118.5 PNdb side-line noise and 106 EPNdb community noise were:

		$\Delta R \sim$ N.Mi. NO SUBSONIC LEG	$\Delta R \sim$ N.Mi. 350 N.Mi. SUBSONIC LEG
° Afterburning turbojet:	Multi-tube Suppressor	-290 to -345	-260 to -435
° Dry Turbojet:	Unsuppressed	-350	---
	4 PNdb Suppressor	-210	-260
° Duct burning turbofan:	Unsuppressed	-390	---
	4 PNdb Suppressor	-320	-305

The above data show that the dry turbojet with a 4 PNdb suppressor will give the best range when no subsonic legs are considered in the mission. However, these results indicate that the current after-burning cycle incorporating a tubular suppressor is competitive with the dry turbojet and with the duct burning turbofan for a sideline noise objective of 118.5 PNdb when additional subsonic legs are considered.

No accounting was made for the increased complexity of control for the turbofan engines or the degree of risk of these new engines when compared to an already operating engine. Furthermore, possible tolerances in the parametric engine weights and performance could lead to additional range differences of [illegible] to [illegible] n.mi.

Whether or not the above conclusion would hold for even lower side-line noise level constraints of say 106 EPNdb (current FAA [illegible] for new subsonic aircraft) is unknown. It is recommended that the study should be expanded to include sideline noise levels down to 106 EPNdb.

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This study bases range comparisons upon standard day conditions. The objective is Paris-New York capability on a hot day (STD + [illegible]°F). Previous studies have shown that some fan engines may have less range loss on hot days than turbojets. This factor should be considered in further studies.

Also it is recommended that this study be expanded to include single and dual rotor mixed burning fans.

[illegible]

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LIST OF FIGURES (Cont'd)

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3. [illegible]-[illegible]00-1, Rev. A, "Production Airplane Performance Objectives, Design Criteria and Requirements", December 1[illegible], 1[illegible].

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8. [illegible]-1, "[illegible] Parametric Engine Library - Design."

9. [illegible]-3, "[illegible] Parametric Engine Library - Acoustics".

10. [illegible]-4, "[illegible] Parametric Engine Library - Weights".

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[illegible].0 NOMENCLATURE

A/B	afterburning	
A/P	airplane	
BPR	bypass ratio	
$C_{D_{POD}}$	drag coefficient for four pods	
EPNdb	unit of effective perceived noise level	
F_n	installed net thrust	lb
L/D	airplane lift to drag ratio	
M	Mach number	
MTW	maximum taxi weight	lb
N.MI.	nautical miles	
OEW	operating empty weight	lb
P/L	payload	
PNdb	unit of perceived noise level	
q	dynamic pressure	lb/ft²
R/C	rate of climb	ft/min
RF	range factor	
R_{fan}	fan pressure ratio	
R_p	overall compressor pressure ratio	
$\frac{F-D}{D}$	thrust minus drag over drag	
TSFC	thrust specific fuel consumption	lb/hr/lb
W_a	sea level static engine airflow	lb/sec

3.0 INTRODUCTION

In the fall of 1968 Boeing changed from the 2707-200 variable sweep SST concept to the 2707-300; an aft-tail, fixed wing configuration. At that time General Electric and Boeing reopened the whole discussion of proper SST engine cycle. The results of the 1968 studies (Refs. 4 and 5) indicated that the basic mission performance is about the same for unsuppressed afterburning turbojets and unsuppressed turbofans. Dry turbojets, when sized to meet minimum climb thrust margin requirements were deficient in range when compared to an unsuppressed afterburning turbojet. NASA Lewis studies (Refs. 6 & 7) in March and June 1969 confirmed these results but noted two important differences:

a) Turbofans appear superior to turbojets when large subsonic legs are included (Ref. 6).

b) In the absence of an effective noise suppression device, a dry turbojet is somewhat superior to the afterburning turbojet when engine noise is a consideration (Ref. 7).

This study re-examines the relative merits of afterburning turbojets, turbofans, and dry turbojets with respect to range, subsonic performance and airport sideline noise constraints of 125 and 11[illegible] PNdB at 1500 ft. The 125 PNdB sideline noise constraint is the initial Boeing-FAA contract objective and the 11[illegible] PNdB noise constraint was the Boeing-G.E. production airplane objective at the time this study was started, Ref. 2.

This study differs from previous ones in three important respects:

1) engine technology is based on high turbine inlet temperatures consistent with initial service in the 19[illegible]-80 time period. The engines were selected from a parametric family of study

engines developed by Boeing (Ref. [illegible]).

2) the effect of large subsonic legs has been considered.

3) an attempt has been made to include detailed configuration effects such as rebalance, secondary [illegible] effects, and gear length rise for constant tail clearance.

6.0 STUDY GROUND RULES

Baseline Airplane

The baseline for this study was the 298 passenger production airplane described in Ref. 1. The "Potential Production Technology" aerodynamic and weight improvement programs as well as the reduced reserves assumed in Ref. 1 were retained. The basic mission profile is shown in Figure 1. A general arrangement drawing of the airplane is shown in Figure 2.

Engine Sizing Criteria

The parametric engines were initially sized for maximum range subject to the following constraints:

- Airport noise = 118.5 PNdb at 1500 ft. sideline. (Std. +10°C day) (Ref. 2)
- FAR takeoff field length ≤ 12,400 ft. (Std. +15°C day). (Ref. 3)
- $\left(\frac{T-D}{W}\right)_{min} \geq .3$ (Std. day).
- Initial cruise corridor ≥ 4000 ft. (Std. day).

After a best engine was selected for each cycle, additional constraints were added:

- Community noise ≤ [illegible] EPNdb at 3.5 n.mi., R/C [illegible] FPM, Std +10°C.
- Community height ≥ 1500 ft.
- Airport noise at 1500 ft. sideline (Std. +10°C)
  - a) unrestricted
  - b) 125 PNdb (Contract objective)
  - c) 118.5 PNdb (Boeing-G.E. objective).

Acoustics data for airport and community noise evaluation for engine sizing are given in Ref. 9.

OEW Effects

Each parametric engine was substituted for the baseline GE4/J5C suppressed afterburning turbojet. Total weight and balance effects on the configuration due to engine pod substitutions were accounted for. These included secondary OEW effects, landing gear length changes for constant ground clearance and sliding the wing on the body to maintain constant center of gravity limits (Ref. 10).

Drag Analysis

Detailed pod drag evaluations were made and formulae were devised for specific pod shapes and sizes for each engine cycle. These pod drag formulae are presented in Appendix 4. These formulae were then used to calculate pod drags for other pods of a family of engine cycles. Since pod drags were only evaluated at M = 2.7, a generalized variation of $\Delta C_{D_{POD}}$ with Mach number was devised to account for pod drag changes throughout the flight regime. This variation was applied to the $\Delta C_{D_{POD}}$ at M = 2.7 between the parametric pod being studied and the J5P validation pod which was in the airplane drag polar.

Pod drag comparisons of the best engine of each cycle sized to meet 118.5 PNdb sideline noise and 108 EPNdb community noise are shown in Table A7 of Appendix 4. In addition pod sketches of these engines are shown in Figure 24 in Appendix 4.

BASIC MISSION RULES

POTENTIAL PRODUCTION TECHNOLOGY

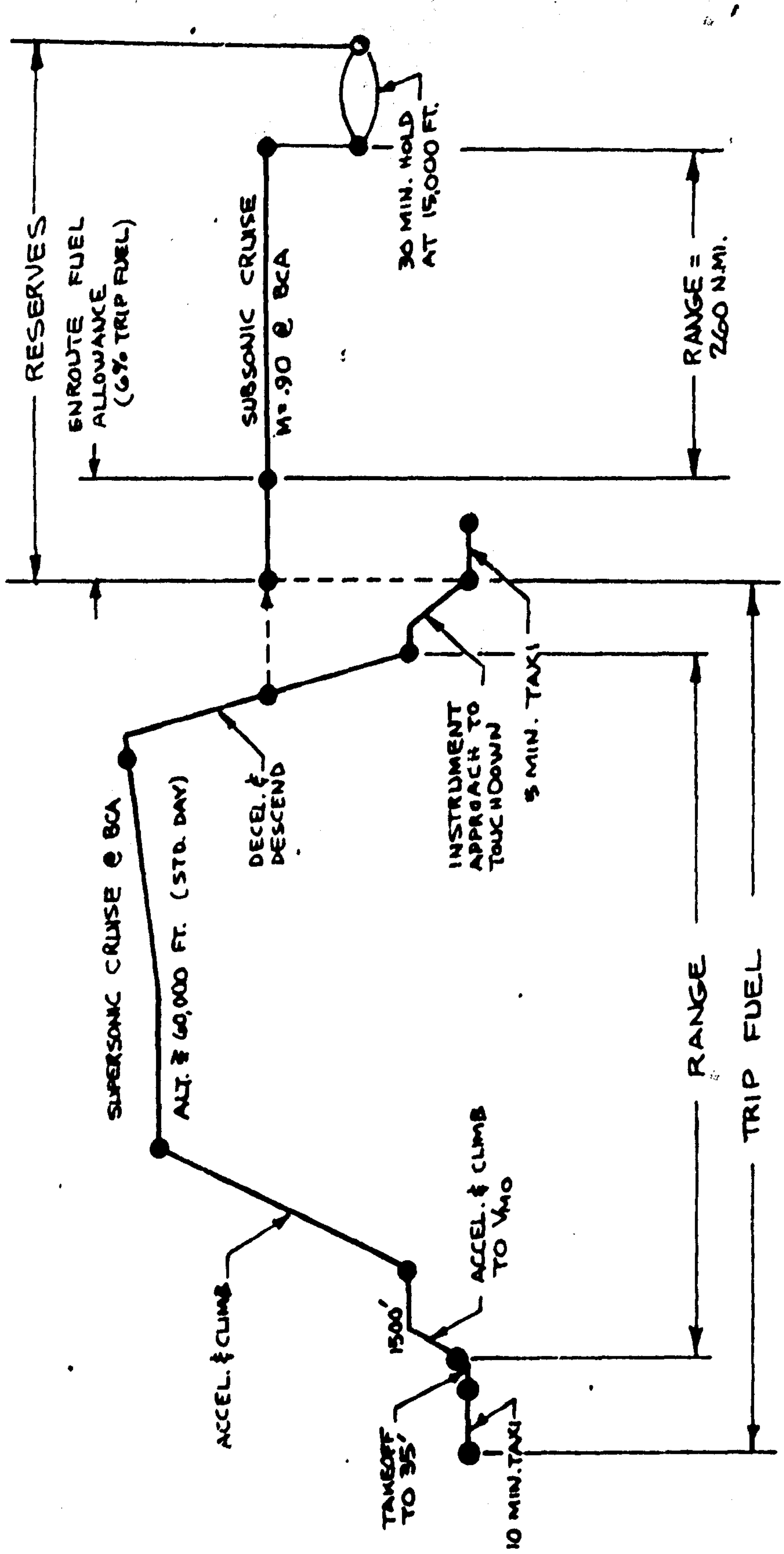

FIG. 1

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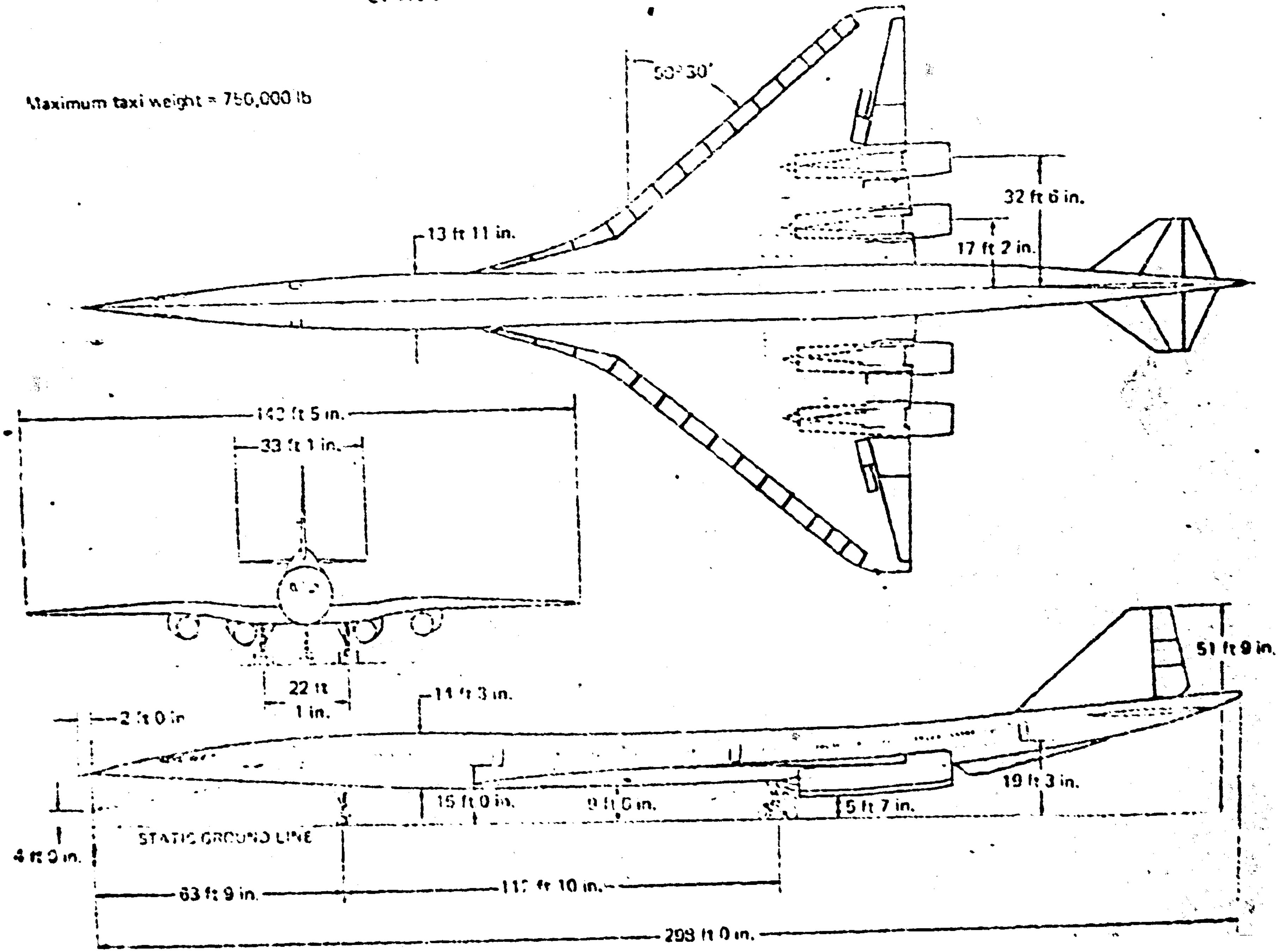
FIGURE 2

GENERAL ARRANGEMENT



7.0 SELECTION OF AFTERBURNING TURBOJET CYCLE

An afterburning turbojet cycle (TJ-2A) with cruise compressor pressure ratio (R_p) of 5 was selected because it most nearly resembled the current General Electric offered production engine and, hence, offered a comparison between the parametric study engines and a real life engine. A brief preliminary study was carried out on afterburning turbojets with R_p's of 4, 5 and 6 to verify range trends only. The results showed range decreasing with increasing R_p, but the range improvement for R_p = 4 as compared to R_p = 5 was only about 30 n.mi. and it was decided to retain R_p = 5 as the baseline afterburning turbojet for comparison with the dry turbojets and duct [illegible]ing turbofans.

Figure [illegible] shows supersonic range performance, climb thrust margin, and airport noise versus engine airflow for the afterburning turbojet. To meet an airport noise level of 1[illegible] PNdb, a [illegible] PNdb sound suppressor was used. The engine with the [illegible] PNdb sound suppressor was estimated to have an [illegible] thrust loss on takeoff and a weight penalty of about [illegible] lb. per engine was assessed for the suppressor.

To meet airport noise levels of 11[illegible].5 PNdb, a large multi-tube suppressor of a design evolved within Boeing was used on the afterburning turbojet. The range loss with this suppressor was estimated to be about 290 to 3[illegible]5 n.mi. This suppressor offered about a 150 n.mi. range advantage over the current General Electric design.

The ground rules for the afterburning turbojet evaluation were to keep engine size small and use jet suppression to reduce sideline noise. To reduce sideline noise [illegible] PNdb by just throttling

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alone would require an engine sized at about 935 lbs/sec. At this large size the range falls off sharply, but some alleviation is obtained by using partial burning in the climb segment from M = .85 to M = 2.7. Despite this, the dry turbojet appears to be the better choice (about 140 n.mi. better) when noise attenuation is sought by throttling. For a proposed follow-on study evaluating lower compressor pressure ratio afterburning turbojets, range optimization for partial burning in climb will be included as part of the study to further understand the impact of augmentation on range.

PARAMETRIC ENGINE STUDY

MTOW = 750000 LB

P/L = 298 PASS.

STD. DAY, M = 2.70

CUTBACK THRUST AT COMMUNITY FOR R/C - 500 FPM

AIRPORT NOISE AT 1500 FT. FROM RUNWAY ℄

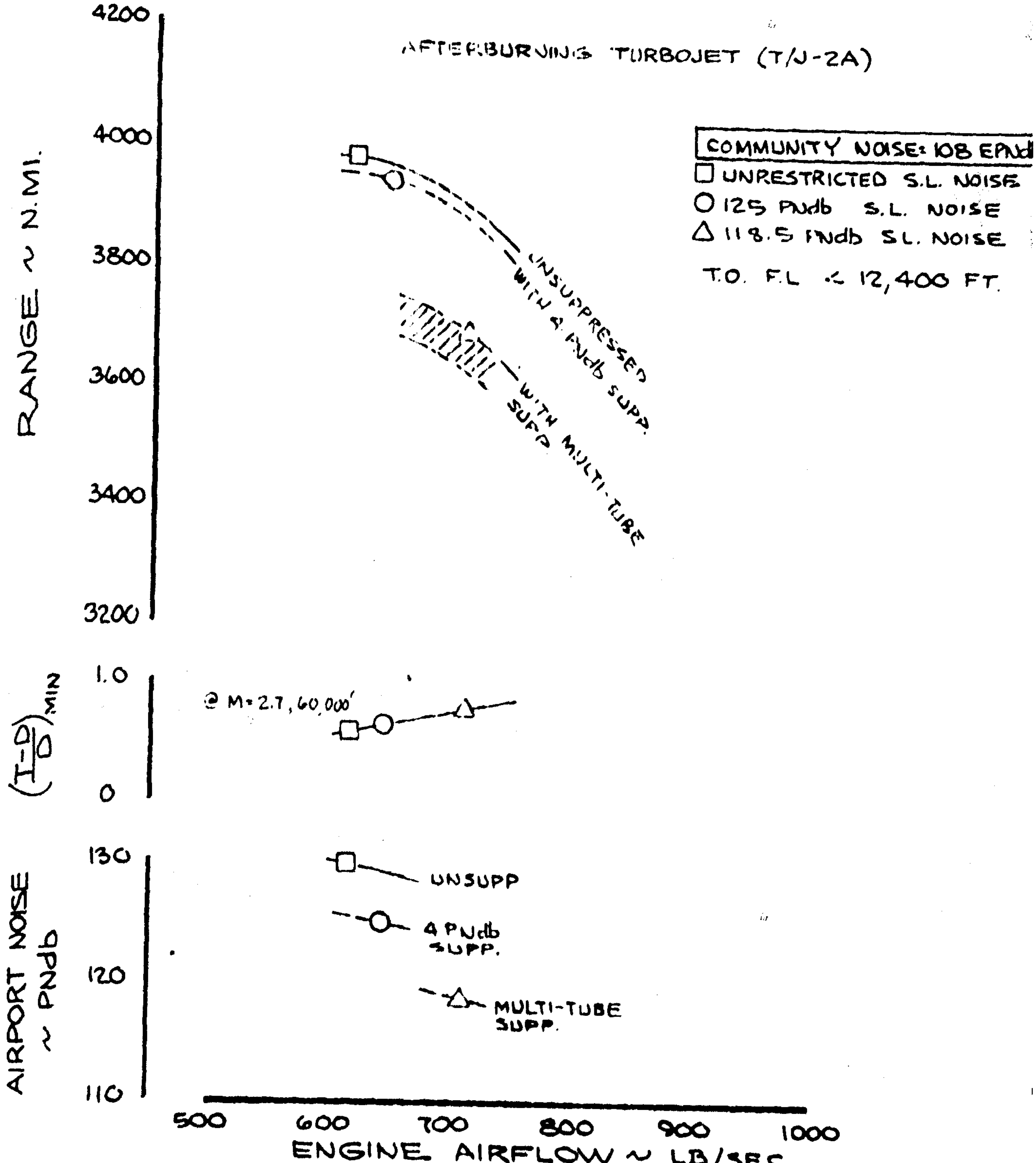

FIG. 3

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AFTERBURNING T/J - 2A
RANGE VS AIRFLOW

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7.0 SELECTION OF DRY TURBOJET CYCLES

Dry turbojets with cruise compressor pressure ratio (R_p) of 4, 5 and 6 were examined. Figure 4 shows the supersonic range performance and climb thrust margins for these three dry turbojets. The dry turbojet with R_p = 5 has the best range performance at a given engine size but is thrust limited in climb. Oversizing of the engines is required to meet a climb requirement of a 4000 foot climb corridor at 60,000 feet and a minimum thrust margin of 0.2.* The dry turbojet with R_p = 4 has the best climb thrust margin of the three turbojets considered and has the best range performance when sized for 116.5 PNdb sideline noise.

Figure 5 shows the effect of subsonic legs on mission range for the three dry turbojets sized for 116.5 PNdb airport noise and a 4000 foot climb corridor capability at initial cruise. These data show that increasing cruise R_p slightly alleviates the fall off of range with subsonic leg length. However, the differences in mission range loss with, say, a 600 n.mi. subsonic leg are small. The R_p = 4 dry turbojet (TJ-1D, PPID-113) was, therefore, selected as the best dry turbojet for the engine cycle comparison.

Figure 6 shows the effect of climb, cruise, and reserves on range as a function of cruise R_p for the dry turbojets sized at 1000 lbs sec airflow. Also shown are the weight and drag effects on range as a function of cruise R_p. A comparison of detailed mission tabulations of the three dry turbojets is shown in Figure A.2 of the Appendix.

---

*Ground rule devised for afterburning turbojet cycle. It has not been justified for alternate cycles and will be studied further in the follow-on cycle study. The present concern is for range loss at temperatures above std. day if the margin is relaxed.

The selected optimum dry turbojet (TJ-1D) was evaluated for three levels of airport noise while meeting 108 EPNdb community noise restrictions. These results are shown in Figure 16 of Section 10, Cycle Comparison. Both the effect of throttling the engines on takeoff and using a 4 PNdb sound suppressor were investigated. The engines with the 4 PNdb suppressor were estimated to have an 8% thrust loss on takeoff and the weight penalty for the suppressor was estimated to be $300 \times \left(\frac{W_a}{633}\right)^{1.12}$ lb. per engine.

The suppressor is retracted at power cutback for community noise evaluation. The use of a sound suppressor to reduce airport noise is more efficient than oversizing the engine and then throttling it to reduce airport noise. Using a 4 PNdb suppressor on the dry turbojet TJ-1D, the required engine airflow for 118.5 PNdb airport noise and 108 PNdb community noise, is 850 lb/sec. Without the suppressor, the required engine airflow for the same noise restrictions is 920 lbs/sec. The smaller engine size with the 4 PNdb suppressor provides a 140 n.mi. range increase relative to the engine using throttling only to reduce airport noise.

PARAMETRIC ENGINE STUDY

MTW = 750,000 LB
STD. DAY
P/L = 298 PASS.

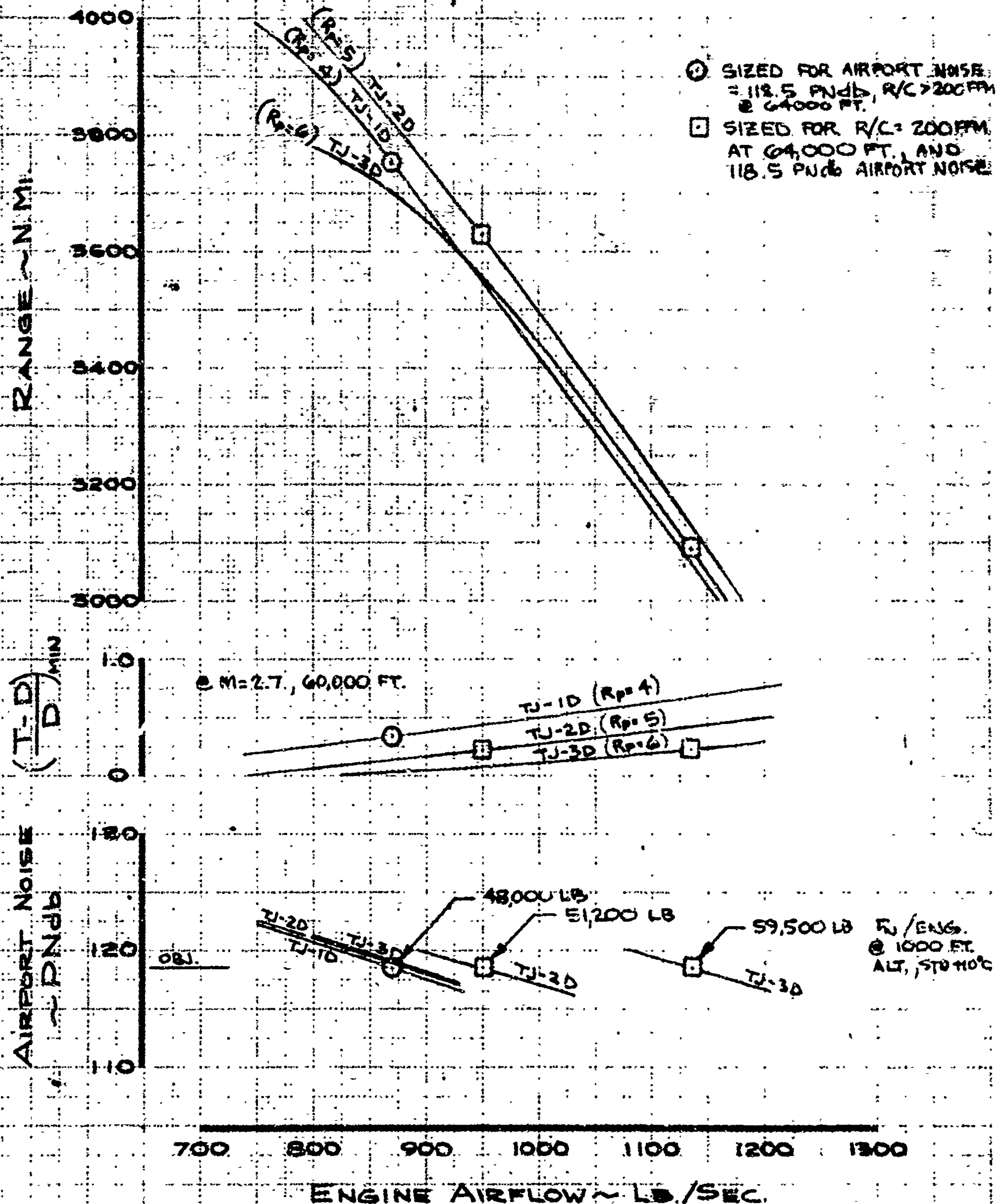

FIG. 4

CALC	Moruss	2-23-70	REVISED	DATE	DRY TURBOJET COMPARISON	D6A11786-5
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PARAMETRIC ENGINE STUDY

DRY TURBOJET COMPARISON
AIRPORT NOISE = 118.5 PNdb

NOTE: ENGINE AIRFLOW SIZED FOR 118.5 PNdb AIRPORT NOISE AND R/C = 200 FPM @ 64000 FT,

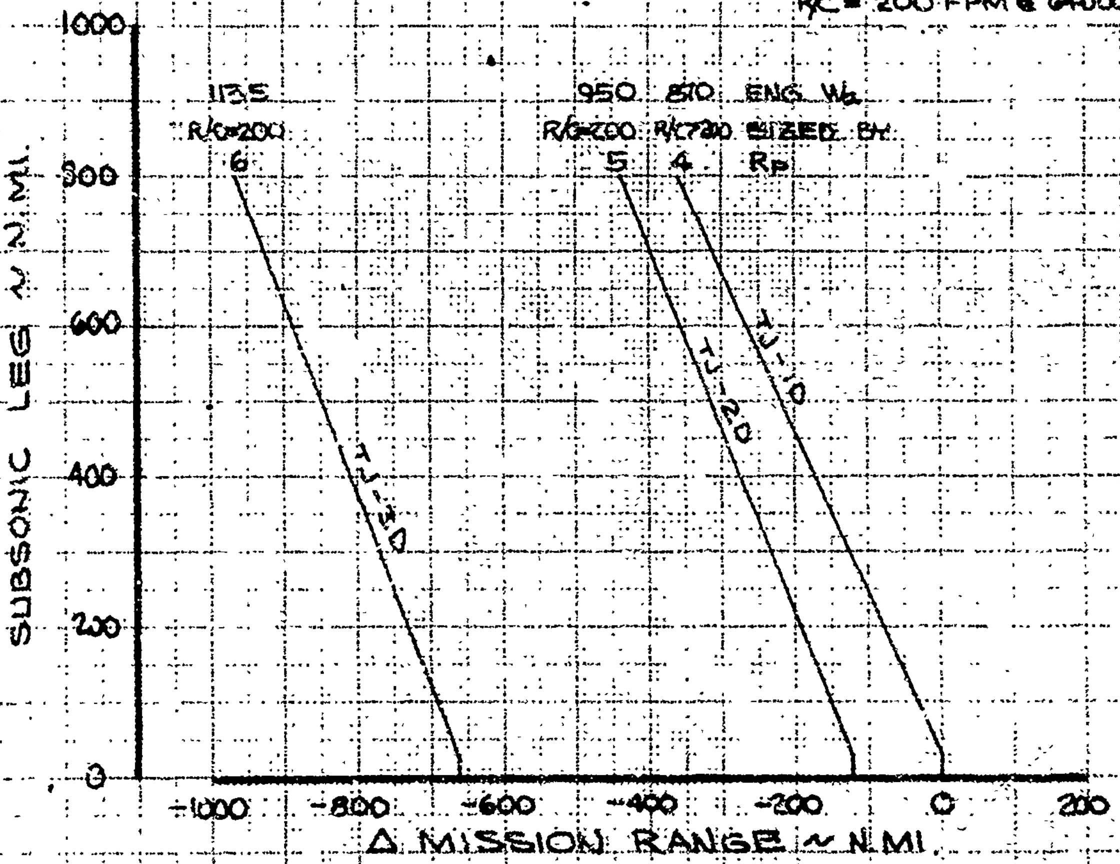

FIG. 5

CALC	AM	3/10/70	REVISED	DATE	DRY TURBOJET COMPARISON, EFFECT OF SUBSONIC LEGS ON MISSION RANGE	D6A11786-5
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PARAMETRIC RANGE TRENDS

DRY TURBOJET COMPARISON
ENGINES COMPARED AT AIRFLOW = 1000 LB/SEC.

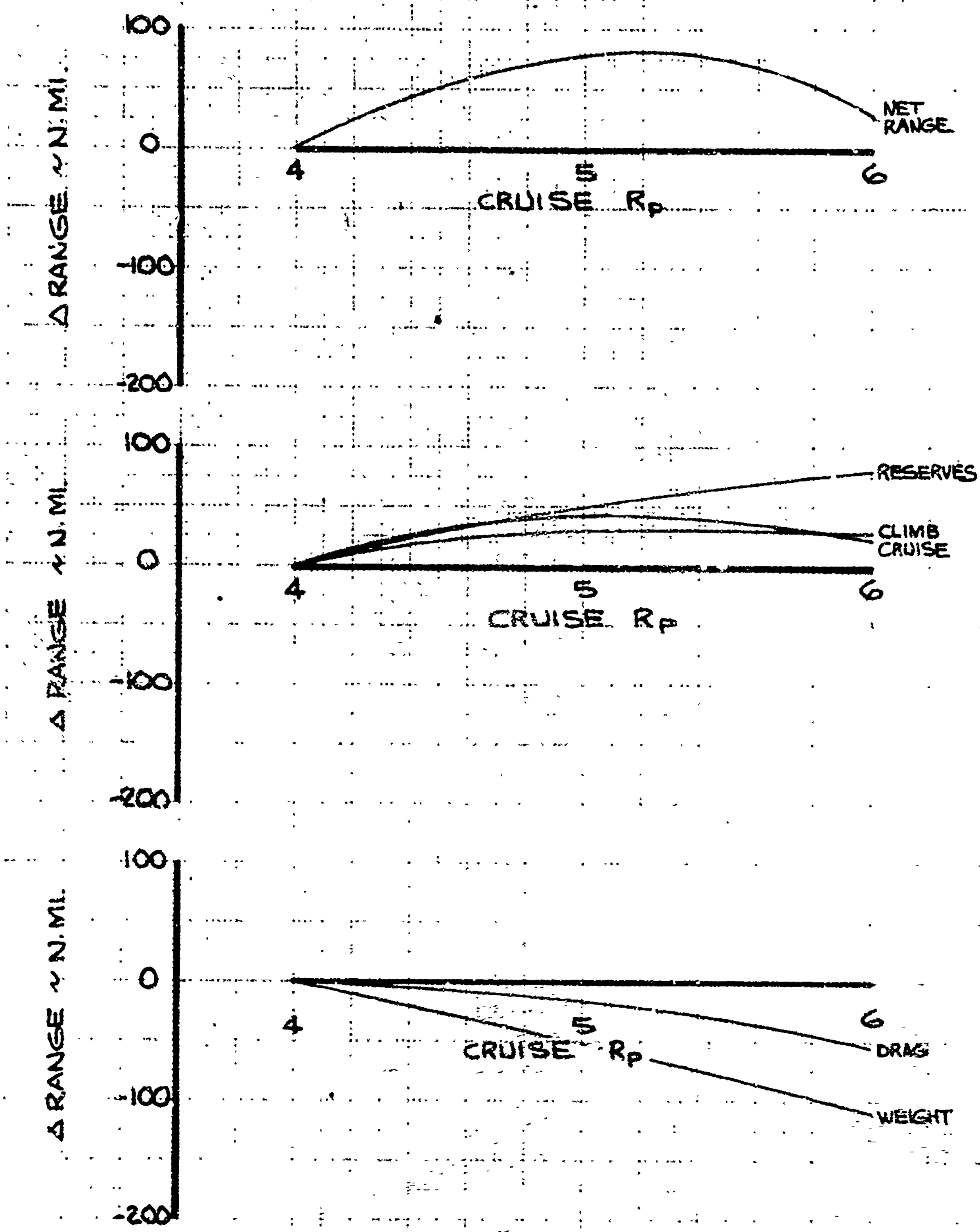

FIG. 6

CALC	AM	3/17/70	REVISED	DATE	DRY TURBOJET COMPARISON, EFFECT OF R_P ON RANGE	D6A11786-5
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9.0 SELECTION OF DUCT-BURNING TURBOFAN CYCLE

The parametric engine family contained 7 duct-burning turbofan engines for mission analysis, Ref. 6. The first group of 4 engines evaluated had cruise bypass ratio between 2 and 3, cruise compressor pressure ratio between 4 and 5, and low cruise fan pressure ratio. The range performance of these "first cut" turbofan engines was 300-600 n.mi. worse than an unsuppressed afterburning turbojet, Appendix 3. From these "first-cut" turbofans, parametric range trends were established that indicated improved range performance with decreasing bypass ratio and increasing fan pressure ratio.

Nearest neighbors around a turbofan with bypass ratio = 1.0, compressor pressure ratio = 5.0, and medium fan pressure ratio were evaluated to select the optimum engine. The nearest neighbor method of selecting an optimum was based on the assumption that only one maximum exists. This reduced the number of additional turbofan engines to evaluate to 7.

The 7 duct burning turbofans were examined to evaluate the effect on range of cruise bypass ratio (BPR), cruise compressor pressure ratio (R_p), and cruise fan pressure ratio (R_{Fan}). Figure 7 shows supersonic range performance and climb thrust margins for duct burning turbofans with cruise BPR = 0.5, 1.0, and 1.5. Cruise R_p = 5.0 and cruise R_{Fan} = 2.5 were held constant. These data show that turbofan TF7 with BPR = 1.0 has the best range performance with engines sized for 118.5 PNdB airport noise and 12,400 foot F.A.R. takeoff field length.

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Figure 8 shows the effectof subsonic legs on mission range r the three turbofans with cruise BPR = 0.5, 1.0, 1.5. These data show that subsonic cruise performance improves sharply by increasing cruise BPR from 0.5 to 1.0, then moderately by increasing BPR from 1.0 to 1.5. TF7 with a BPR = 1.0 (max. range all supersonic) is a good compromise choice for subsonic performance.

Figure 9 shows supersonic range performance and climb thrust margin for cruise BPR = 1.0 duct burning turbofans with cruise R_{Fan} = 2.5 and cruise R_p = 4, 5, and 6. These data show that turbofan TF7 with cruise R_p = 5.0 has the best range performance with engines sized for 118.5 PNdB airport noise and 12,400 foot F.A.R. takeoff field length.

Figure 10 shows the effect of subsonic legs on mission range for the three turbofans with cruise R_p = 4, 5, and 6. These data show that subsonic cruise performance improves sharply by increasing cruise R_p from 4 to 5, then moderately by increasing cruise R_p from 5 to 6. These data show TF7 with a R_p = 5 (max. range all supersonic) to be good compromise choice for subsonic performance.

Figure 11 shows supersonic range performance and climb thrust margin for cruise BPR = 1.0 duct burning turbofans with cruise R_p = 5.0 and cruise R_{Fan} = 2.0, 2.5, and 3.0. These data show that increasing cruise R_{Fan} improves supersonic range performance at a given engine size. However, when the engines are sized for 118.5 PNdB airport noise, turbofan TF7 with cruise R_{Fan} = 2.5 has the best range performance.

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The effect of subsonic legs on mission range for the above turbofans are shown in Figure 12. These data show that turbofan TF7 with cruise R_{Fan} = 2.5 has the best subsonic cruise performance.

Parametric range trends showing the effect of cruise BPR, R_p, and R_{Fan} for the duct burning turbofans are shown in Figure 13. With the engines compared at a constant airflow, these data indicate optimum range performance for a turbofan with cruise BPR = 1.0, R_p = 5.0, and R_{Fan} = 2.5 to 3.0.

Figure 14 shows the incremental effect of cruise BPR, R_p, and R_{Fan} on the climb, cruise, and reserve portions of the mission range. These data show that cruise range increases with decreasing BPR and R_p but increasing R_{Fan}. Climb range increases with decreasing cruise BPR but increasing cruise R_p and R_{Fan}. Increasing cruise BPR and R_p reduces reserve fuel, thus increasing range, but cruise R_{Fan} has little effect on reserves.

Figure 15 shows the incremental effects of cruise BPR, R_p, and R_{Fan} on mission range because of weight and cruise pod drag changes. These data show that weight decreases with increasing cruise BPR and R_{Fan}, thus increasing range. Weight increases with cruise R_p. These data show that engine pod drag is a minimum at cruise BPR = 1.0, R_p = 5.0, and R_{Fan} = 2.5.

The selected optimum duct burning turbofan TF7 was evaluated for sideline noise levels of 118.5 PNdB, 125 PNdB, and 129 PNdB while

meeting 108 EPNdB at the community. These results are shown in Figure 16 of Section 10, Cycle Comparison. Both unsuppressed and suppressed data were evaluated. The penalty for a 4 PNdB sideline noise suppressor is an 8% takeoff thrust loss and a weight increase of $300 \times \left(\frac{W_a}{633}\right)^{1.12}$ lb per engine.

Figure 16 shows that to meet 118.5 PNdB sideline noise, the use of a 4 PNdB sideline noise suppressor allows a 70 n.mi. range increase over the unsuppressed engine.

Tables A.3, A.4, A.5 in the Appendix show detailed mission tabulations of the duct burning turbofans showing the effect of cruise BPR, R_p, and R_{Fan}, respectively. These data are compared at engines sized for 118.5 PNdB sideline noise and 12,400 ft F.A.R. field length.

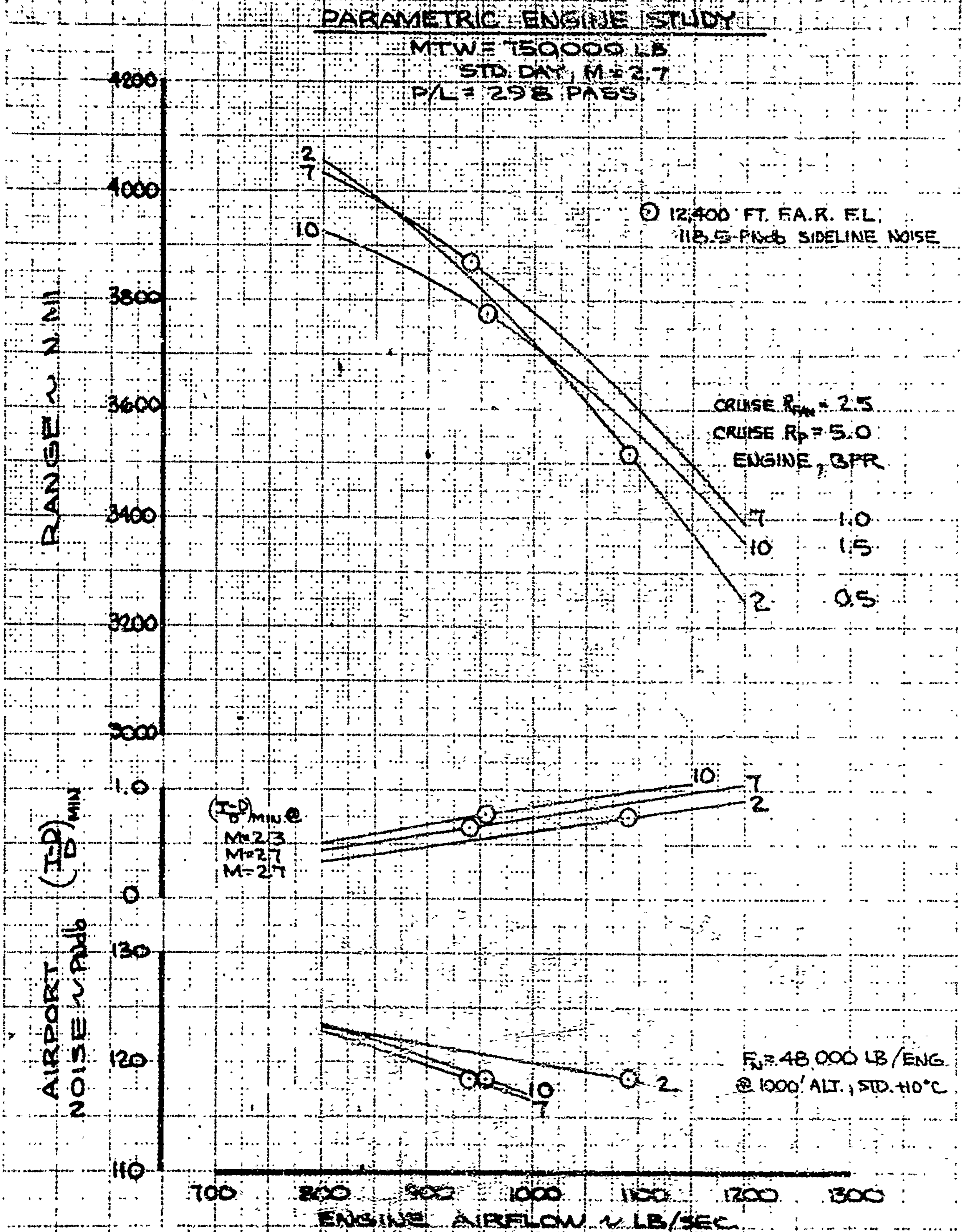

FIG. 7

CALC	AM	3/11/70	REVISED	DATE	TURBOFAN ENGINE COMPARISON, EFFECT OF CRUISE BPR
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PARAMETRIC ENGINE STUDY

MTW = 750,000 LB

STD. DAY

AIRPORT NOISE = 118.5 PNdb

T.O. F.L. = 12,400 FT

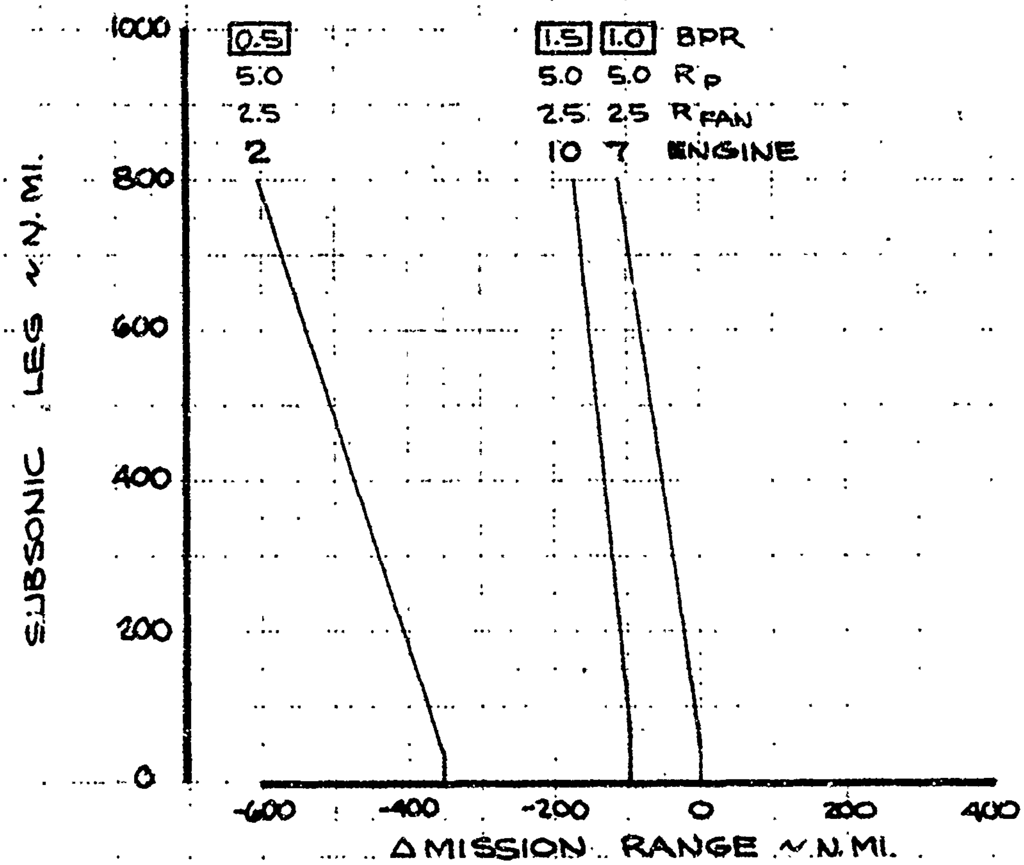


FIG. 8

CALC	AM	3/16/70	REVISED	DATE	TURBOFAN ENGINE COMPARISON EFFECT OF BPR ON MIXED MISSION RANGE	D6A11786-5
CHECK						
APR						
APR					THE BOEING COMPANY	PAGE 32

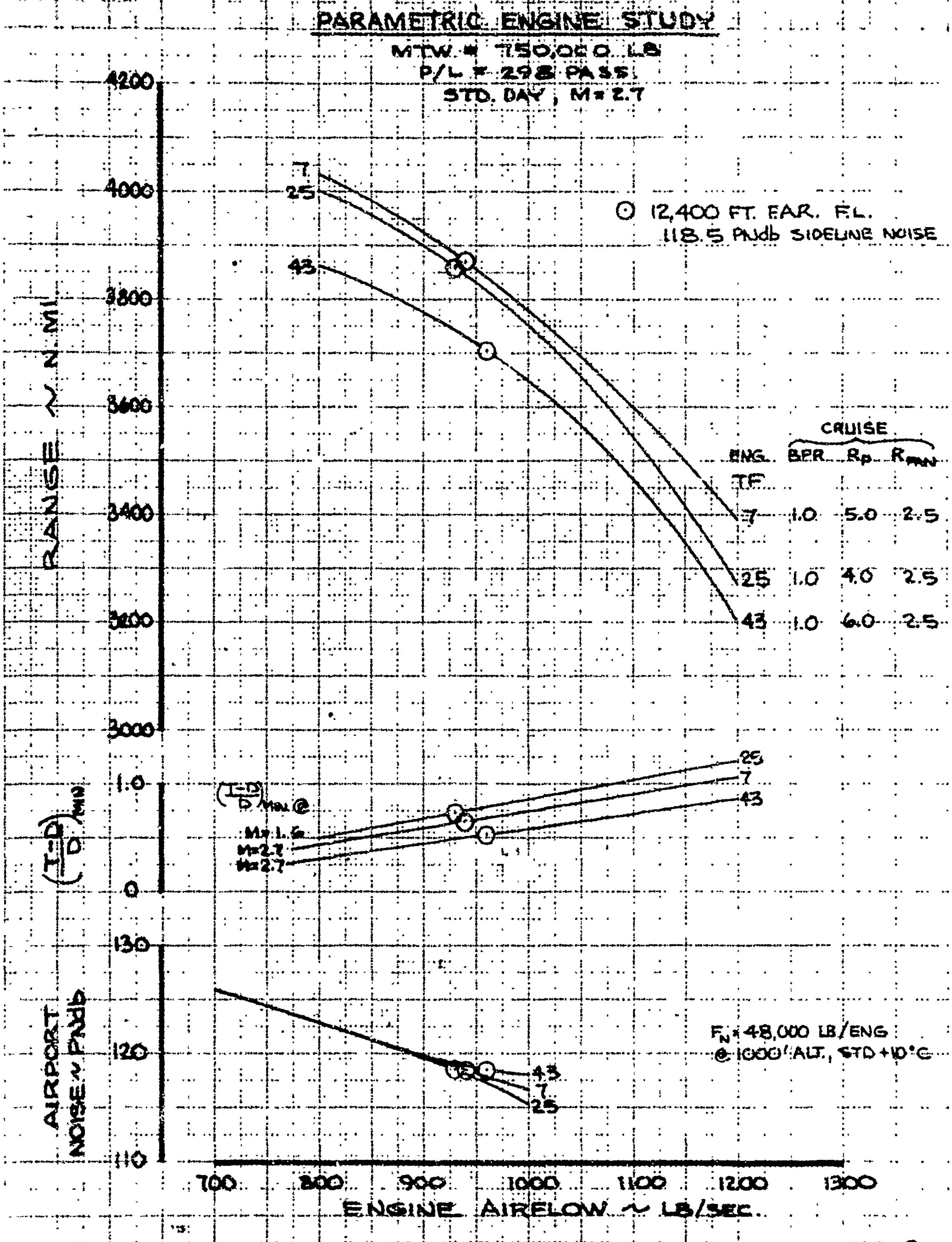


FIG. 9

CALC	AM	3/11/70	REVISED	DATE	TURBOFAN ENGINE COMPARISON, EFFECT OF COMPRESSOR PRESSURE RATIO	D6A11786-5
CHECK						
APR						
APR					THE BOEING COMPANY	PAGE 33

PARAMETRIC ENGINE STUDY

MTW = 750,000 LB

STD. DAY

AIRPORT NOISE = 118.5 PNdb

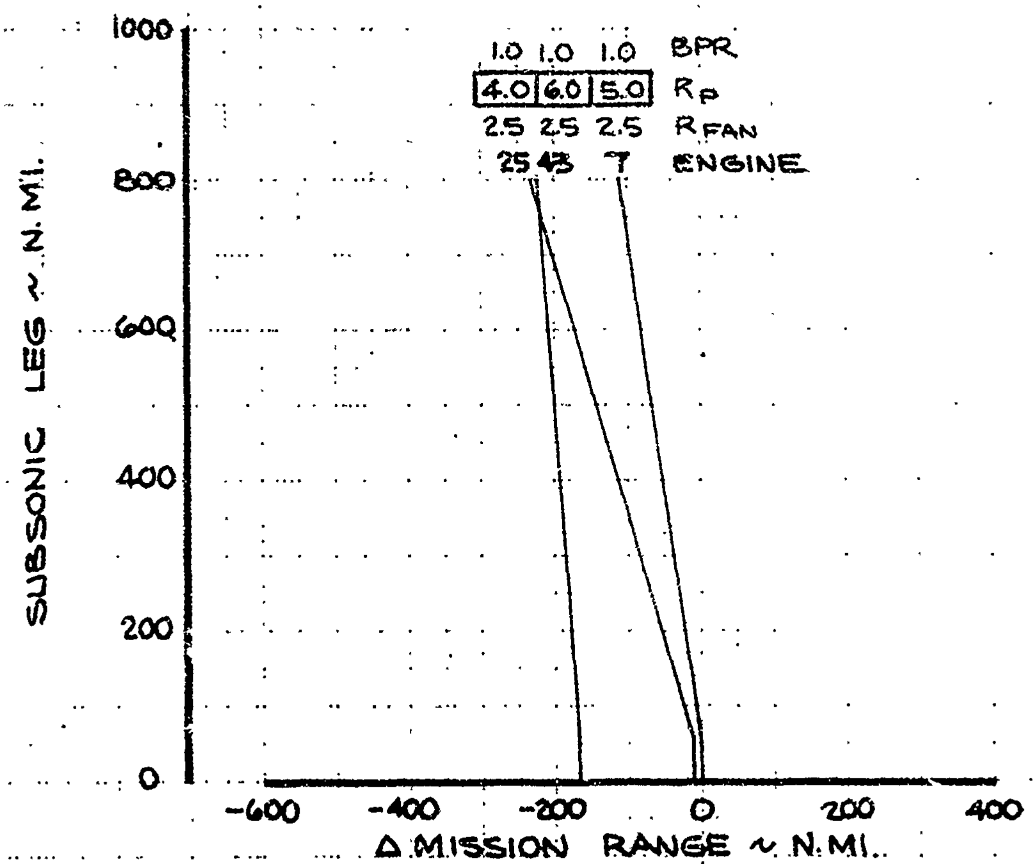


FIG. 10

CALC	AM	3/16/70	REVISED	DATE	TURBOFAN ENGINE COMPARISON, EFFECT OF R_p ON MIXED MISSION RANGE	D6A11786-5
CHECK						
APR						
APR					THE BOEING COMPANY	PAGE 34

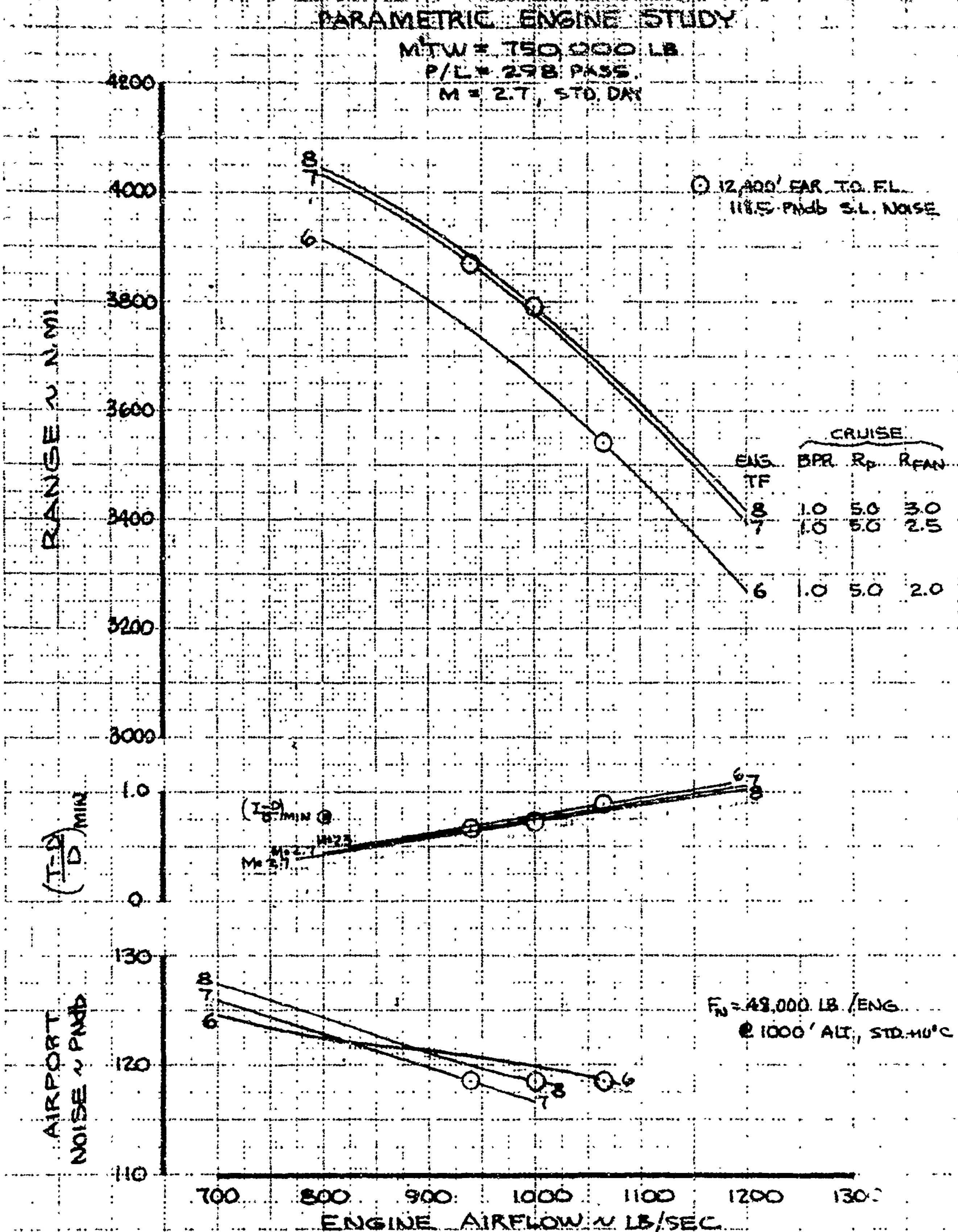


FIG. 11.

CALC	AM	8/11/70	REVISED	DATE	TURBOFAN ENGINE COMPARISON EFFECT OF FAN PRESSURE RATIO	D6A11736-5
CHECK						
APR						
APR					THE BOEING COMPANY	PAGE 35

PARAMETRIC ENGINE STUDY
MTW = 750,000 LB
STD. DAY
AIRPORT NOISE = 118.5 PNdb
T.O. F.L. 2,400 FT.

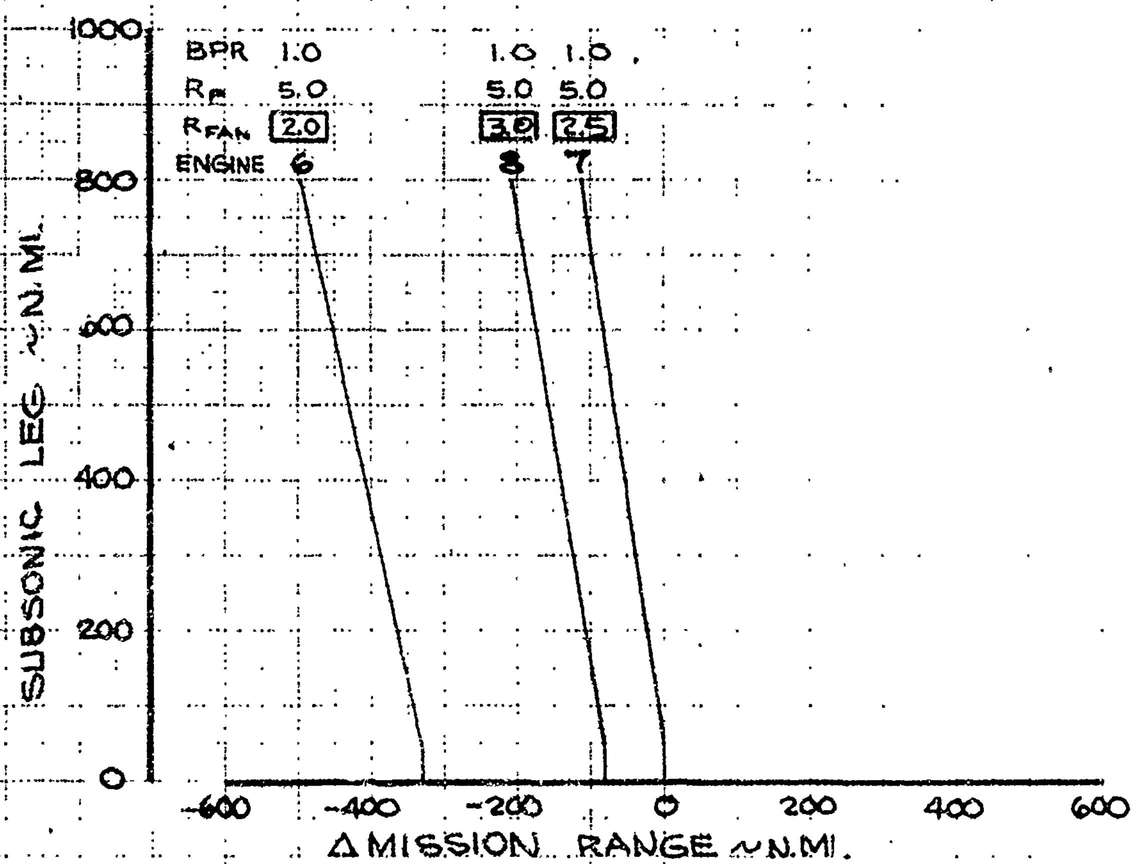


FIG. 12

CALC	AM	3/16/70	REVISED	DATE	TURBOFAN ENGINE COMPARISON EFFECT OF R_{FAN} ON MIXED MISSION RANGE	D6A11786-5
CHECK						
APR						
APP					THE BOEING COMPANY	PAGE 36

PARAMETRIC RANGE TRENDS

TURBOFAN ENGINES

ENGINES COMPARED AT AIRFLOW = 940 LB/SEC

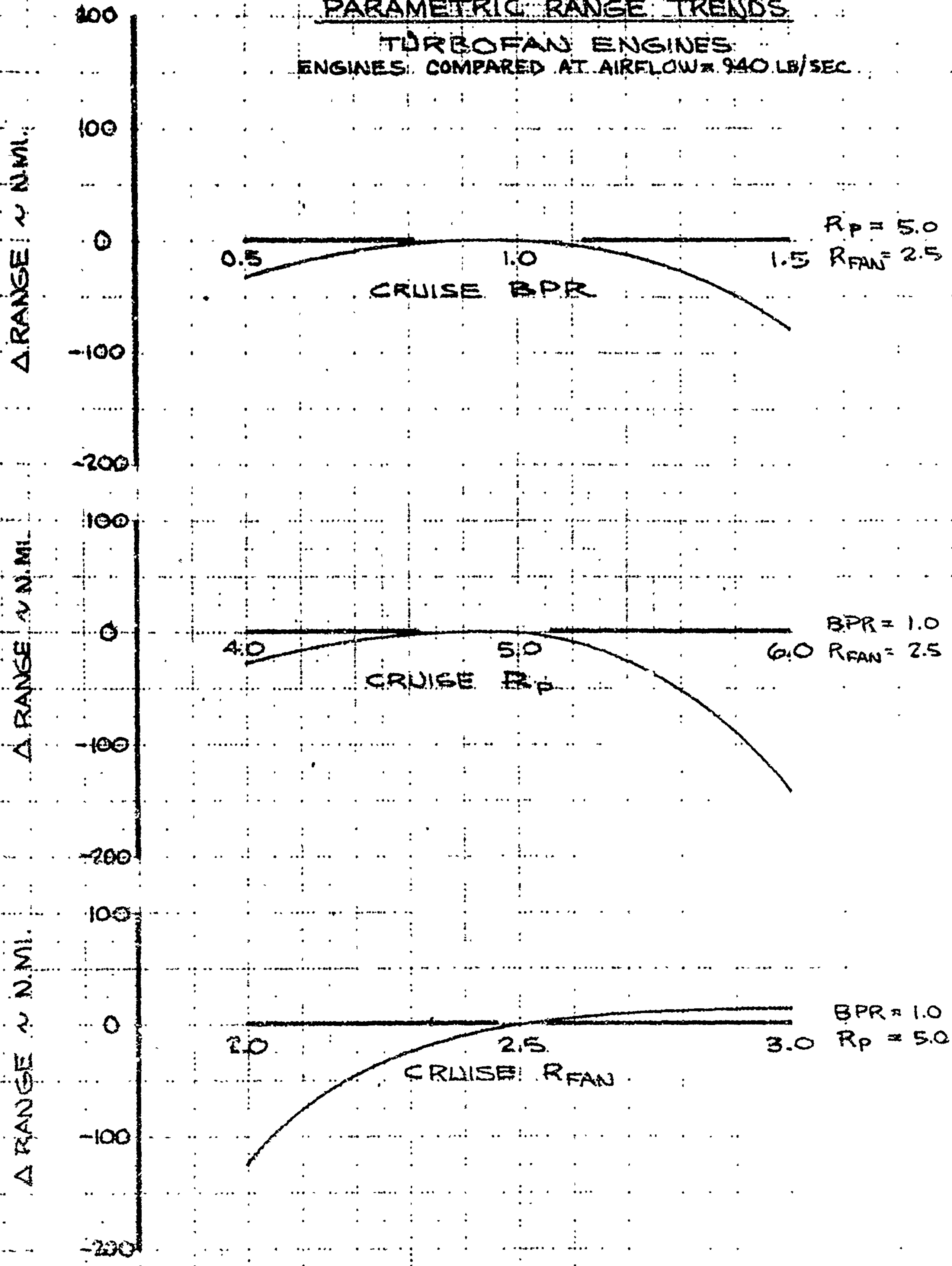


FIG. 13

CALC	AM	3/12/70	REVISED	DATE	TURBOFAN, PARAMETRIC RANGE TRENDS, EFFECT OF CRUISE BPR, R_P & R_{FAN}	D6A11786-3
CHECK						
APR						
APR					THE BOEING COMPANY	PAGE 37

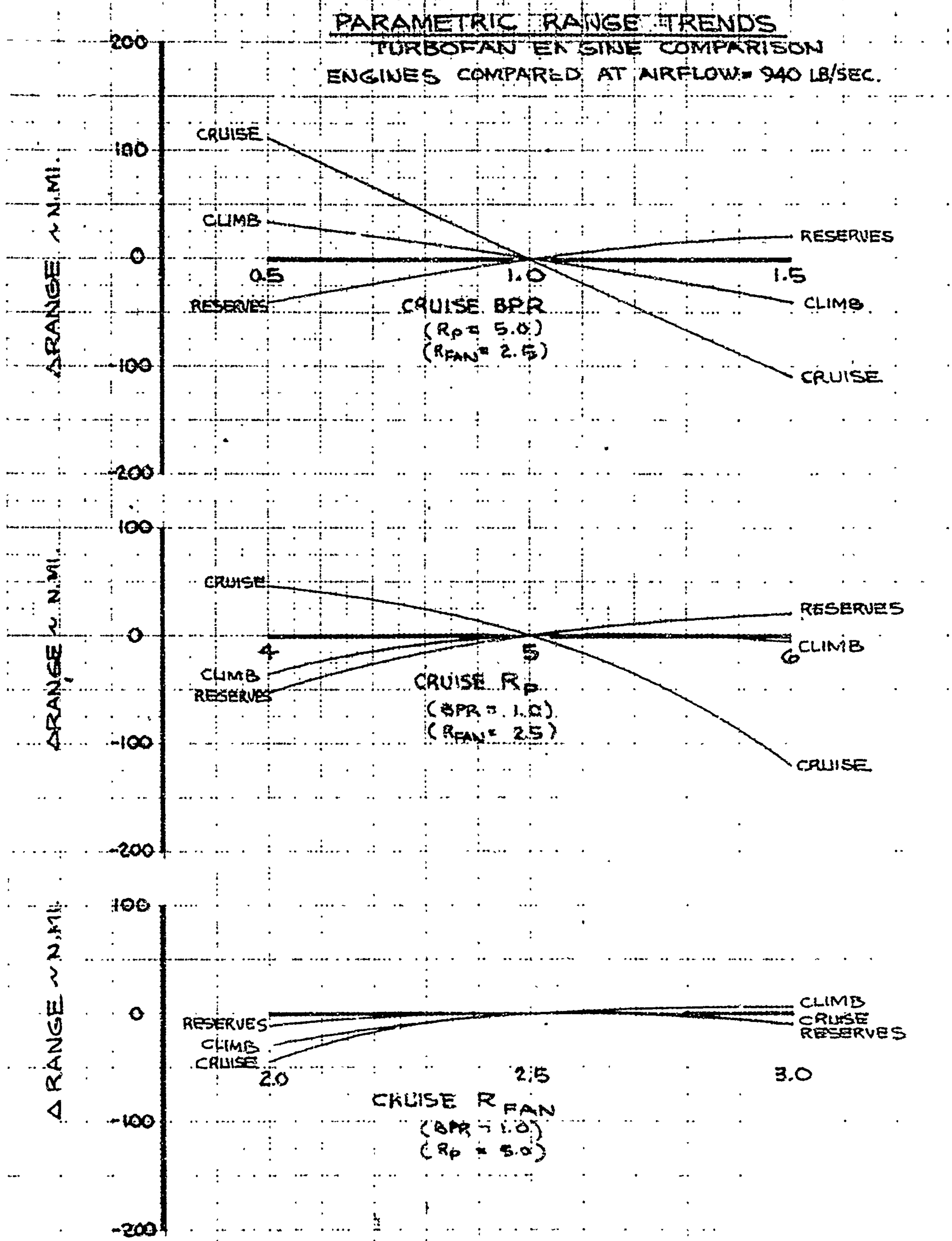


FIG. 14

CALC	AM	3/12/70	REVISED	DATE	TURBOFAN, PARAMETRIC RANGE TRENDS, EFFECT ON CLIMB CRUISE & RESERVES	D6A11786-5
CHECK						
APR						
APR					THE BOEING COMPANY	PAGE 38

PARAMETRIC RANGE TRENDS

TURBOFAN ENGINE COMPARISON

ENGINES COMPARED AT AIRFLOW = 940 LB/SEC.

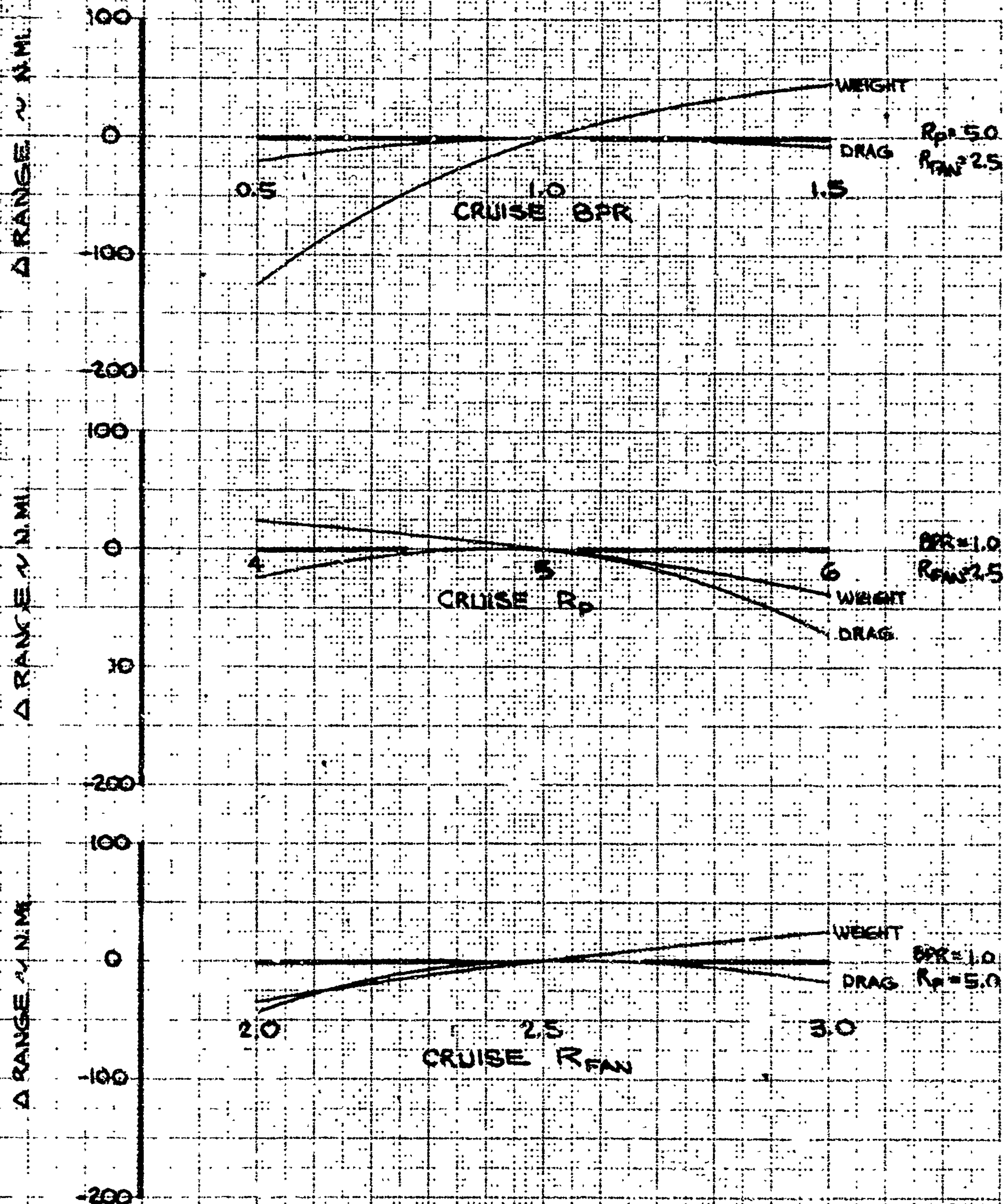


FIG. 15

CALC	AM	5/12/70	REVISED	DATE	TURBOFAN, PARAMETRIC RANGE TRENDS, EFFECT OF WEIGHT AND POD DRAG	D6A11786-5
CHECK						
APR						
APR					THE BOEING COMPANY	PAGE 39

10. CYCLE COMPARISONS AND CONCLUSIONS

This section presents comparisons of the best engine selected from each cycle with the engines sized to meet 118.5 PNdb sideline and 108 EPNdb community noise. In addition, the study was expanded to include cycle comparisons with unrestricted sideline noise (about 129 PNdb) and 125 PNdb sideline noise. The benefit of using a simple 4 PNdb suppressor to meet these sideline noise objectives was also evaluated.

The best engines selected from each type of engine considered were:

1. An afterburning turbojet with cruise compressor pressure ratio (π_p) = 5 which most nearly resembled the GE offered production engine (Section 7).

2. A dry turbojet with cruise compressor pressure ratio (π_p) = 4 which had the best range performance of the three dry turbojets considered (Section 8.0) when sized for airport noise and climb thrust margin.

3. A duct-burning turbofan with cruise bypass ratio (BPR)=1, cruise compressor pressure ratio (π_p) = [illegible], and cruise fan pressure ratio (π_{Fan}) = 2.5. This turbofan had the best range performance of all the turbofans considered (Section 9.0) when sized for airport noise.

The results of this study are shown in Figures 16 and 17. Figure 16 shows comparisons of the three engine cycles and the effects of meeting noise objectives on climb and range performance. Figure 17 shows the effect of subsonic legs on total mission range for each engine.

Figure 16 shows that:

1. For unrestricted sideline noise (about 129 PNdb) the duct burning turbofan accounts for about 70 n. mi. more range than the afterburning turbojet while range with the dry turbojet which is oversized for a 0.3 climb thrust margin is 130 n. mi. less than with the afterburning turbojet.

2. With sideline noise restricted to 125 PNdb, the range with the dry turbojet which is oversized to meet 0.3 climb thrust margin is 90 n. mi. less than range with the afterburning turbojet with 4 PNdb suppression. The range with the turbofan with 4 PNdb suppression is 50 n. mi. more than the range with the afterburning turbojet with 4 PNdb suppression. Without a suppressor, the range with the turbofan is about 30 n. mi. less than the suppressed afterburning turbojet.

3. With sideline noise restricted to 118.5 PNdb, the range with the suppressed dry turbojet and suppressed duct burning turbofan is 80 n. mi. more and 30 n. mi. less respectively than with the suppressed afterburning turbojet. Without a suppressor, the range with the dry turbojet and duct burning turbofan is 60 and 100 n. mi. less respectively than the range with the afterburning turbojet with a multitube suppressor

Figure 17 shows the effect of subsonic legs on mission range for the three selected engines. With the engines sized to meet 118.5 PNdb sideline noise, these data show the turbofan has the best subsonic performance, and the dry turbojet has the worst with range losses of

65 n.mi. and 150 n.mi. respectively, for a nominal 350 n.mi. subsonic leg. With the afterburning turbojet with a parametric convergent-divergent nozzle, the range loss was 90 n.mi. for a 350 n.mi. subsonic leg which makes it fairly competitive with the duct burning turbofan.

The data in Figure 16 show that the dry turbojet with a 4 PNdb suppressor has the least range loss to achieve 118.5 PNdb sideline noise when no subsonic legs are considered in the mission. However, the results of Figure 17 indicate that when subsonic legs are considered the current afterburning cycle is competitive with the dry turbojet and duct burning turbofan for sideline noise objectives of 118.5 PNdb.

Whether or not this conclusion would hold for even lower sideline noise level constraints of say 108 EPNdb (current FAR 36) is unknown. Therefore, it is recommended that the study should be expanded to include sideline noise levels down to 108 EPNdb. In addition, mixed burning turbofans with open nozzle and throttling should be studied as well as lower compressor pressure ratio afterburning turbojets and dry turbojets. Since the use of 4 PNdb jet suppression to reduce airport noise was shown to be more efficient than oversizing and then throttling the engine, it is also recommended that suppressors that achieve more than 4 PNdb sideline noise reduction be studied.

This study based range comparisons upon standard day conditions. The objective is Paris-New York capability on a hot day (STD. + [illegible]°C). Previous studies [illegible] fan engines to have considerably less

range loss on hot days than turbojets. This factor should be considered in further studies.

PARAMETRIC ENGINE STUDY

MTW = 750,000 LB
P/L = 298 PASS.
STD. DAY, M = 2.7
CUTBACK THRUST AT COMMUNITY FOR R/C = 500 FPM
AIRPORT NOISE AT 1500 FT FROM RUNWAY ℄

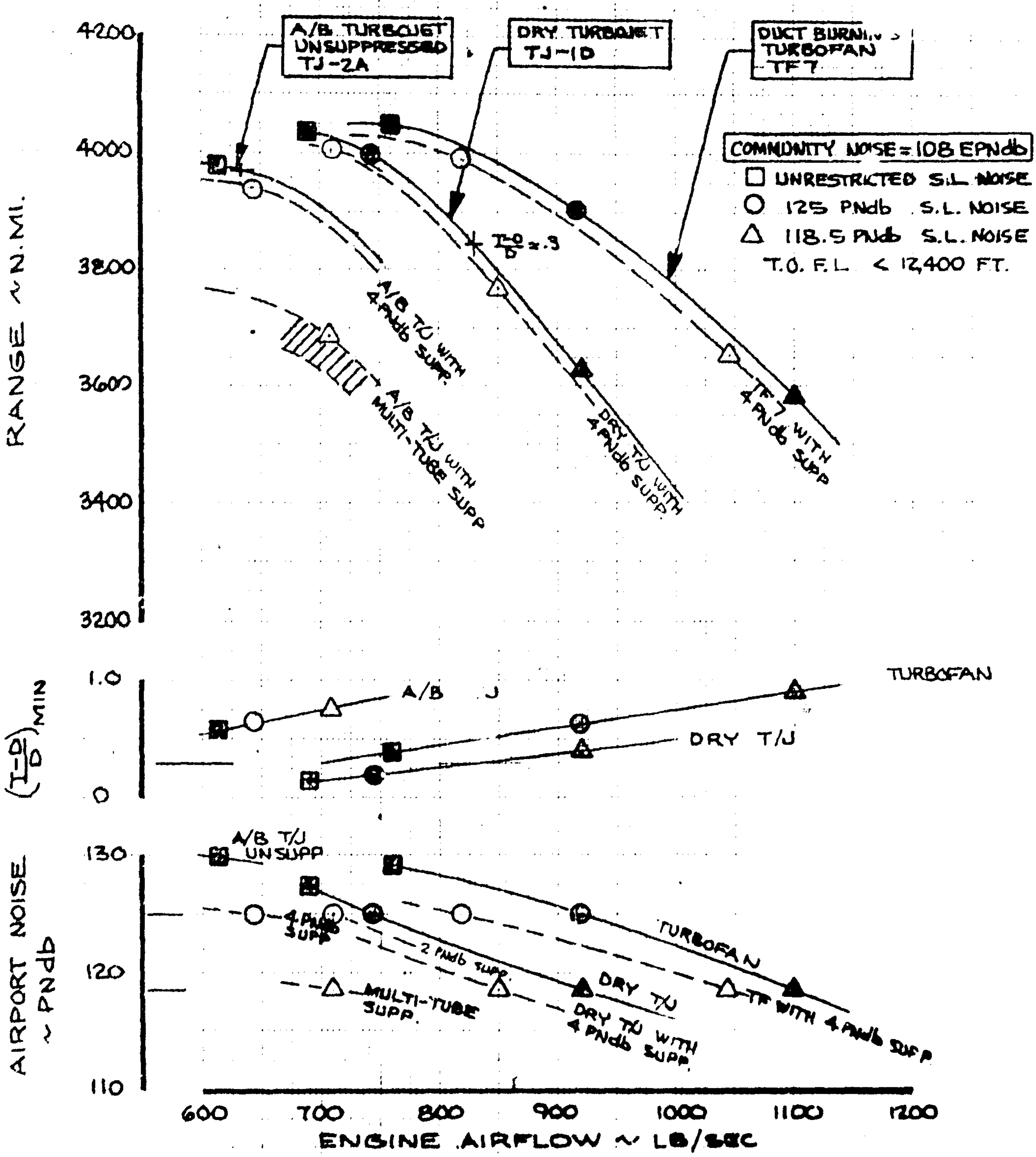


FIG. 16

CALC	[illegible]	3/20/70	REVISED	DATE	ENGINE CYCLE COMPARISON RANGE VS. AIRFLOW SUMMARY
CHECK					
APD					
APD					THE BOEING COMPANY

D6A11???-1

PARAMETRIC ENGINE STUDY

ENGINES SIZED FOR: AIRPORT NOISE ≤ 118.5 PNdb
COMM. NOISE ≤ 108 EPNdb
F.L. ≤ 12,400 FT.

MTW = 750,000 LB
P/L = 298 PASS.
STD. DAY

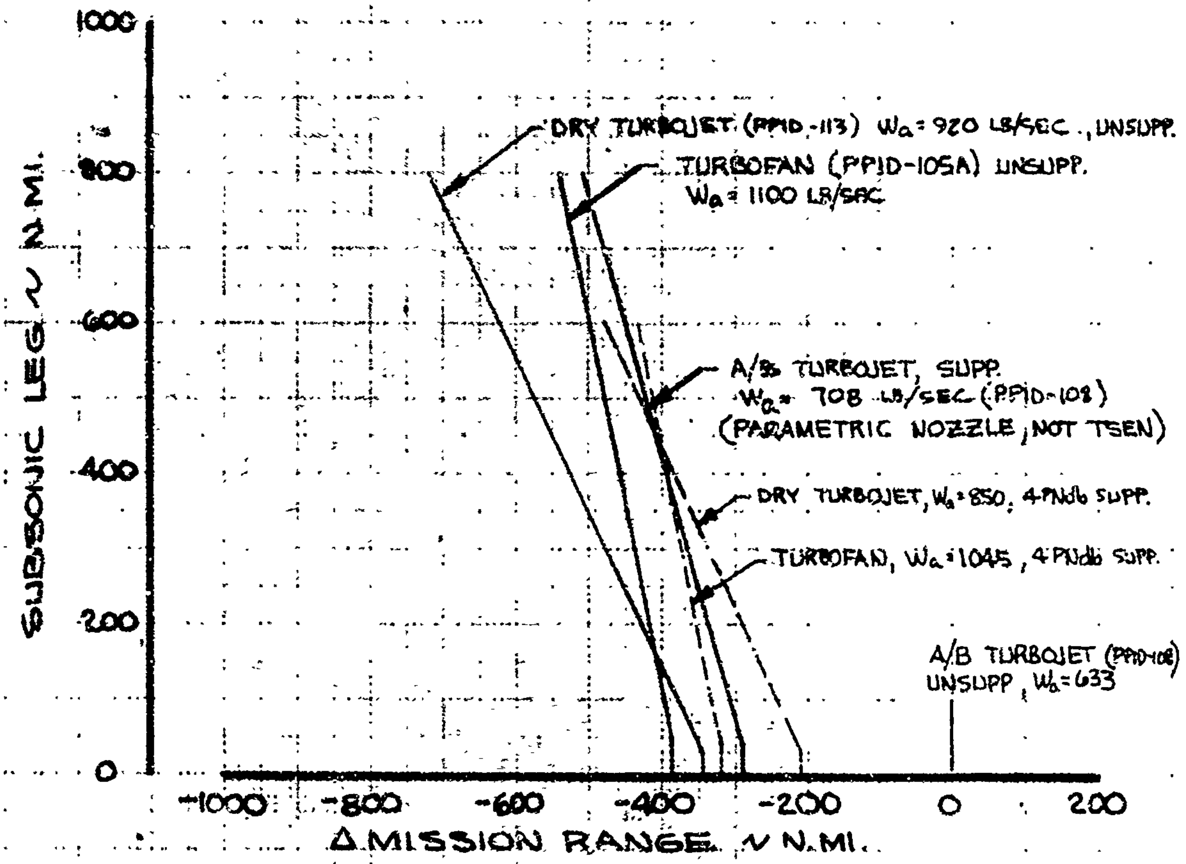


FIG. 17.

CALC	AM	5/12/70	REVISED	DATE	EFFECT OF SUBSONIC LEGS ON MISSION RANGE
CHECK					D6A11786-5
APR					
APR					THE BOEING COMPANY — PAGE 45

APPENDIX 1

DETAILED MISSION TABULATIONS

1. A/B turbojet vs. dry turbojet vs. turbofan.
2. Dry turbojet.
3. Fan, Effect of
    a. BPR
    b. Rp
    c. RFan

A/P = -300 PRODUCTION
M.T.W. = 750,000 LB
TEMP = STD.

TABLE A.1

ENGINE - / AIRFLOW	TJ-2A / 633 (UNSUPP)	TJ-1D / 870	TF 7 / 940
CRUISE BPR	—	—	1.0
CRUISE R_P	15.0	4.0	5.0
CRUISE R_{FAN}			2.5
WEIGHTS:			
O.E.W.			
ΔO.E.W.			
O.E.W.+ΔO.E.W. ~ LB	308100	326140	327,730
RANGE ~ N.MI.	3969	3752	3871
TAXI FUEL ~ LB	4131	4983	3741
TAKEOFF FUEL ~ LB	4786	3195	2400
SUBSONIC CLIMB (TO M=0.88)			
FUEL ~ LB	18395	17601	15437
DISTANCE ~ N.MI.	38	24.4	46.3
SUPERSONIC CLIMB:			
FUEL ~ LB	66,550	66852	57442
DISTANCE ~ N.MI.	260	407	220
CRUISE			
C_D POD @ M=2.7 ~ COUNTS	1.8	3.5	3.3
(N.MI./LB) INITIAL	.01234	.01258	.01239
WT = 550,000 LB: ALTITUDE ~ FT.	60000	68217	63020
WT = 550,000 LB: $(L/D)_{MAX}$	8.10	7.855	7.950
WT = 550,000 LB: $(L/D)_{CRUISE}$	7.763	7.837	7.841
WT = 550,000 LB: F_N/q	22.890	33.484	26.135
WT = 550,000 LB: TSFC	1.492	1.4903	1.4873
WT = 550,000 LB: RF	8055	8158	8164
FUEL ~ LB	227156	205809	225937
DISTANCE ~ N.MI.	3426	3074	3370
(N.MI./LB) FINAL	.01850	.01797	.01813
DESCENT			
FUEL ~ LB	3628	3739	3863
DISTANCE ~ N.MI.	246	247	235
ILS FUEL ~ LB	1512	1606	1029
RESERVE FUEL ~ LB	53459	58976	50129
6% MISSION FUEL ~ LB	19569	18161	18591
MISSED APPROACH FUEL ~ LB			
ALTERNATE (250 N.MI.)			
FUEL ~ LB	17193	20458	15980
AVG. CRUISE: RF	6003	5339	6742
AVG. CRUISE: L/D	13.92	13.41	13.68
AVG. CRUISE: TSFC	1.197	1.2971	1.0472
AVG. CRUISE: WEIGHT ~ LB	399,000	421,994	416093
HOLD			
MACH	.475	.475	.475
FUEL ~ LB	16,697	20,357	15,558
L/D	14.80	14.32	14.35
TSFC	1.296	1.4537	1.1171
AVG. WT. ~ LB	382,000	401,586	400,324
ILS APPROACH			

A/P = -300 PRODUCTION
M.T.W. = 750,000 LB
TEMP = STD

TABLE A.2

ENGINE / AIRFLOW	TJ-10 /870	TJ-20 /950*	TJ-30 /1135*
CRUISE BPR CRUISE R_P CRUISE R_{FAN}	4	5	6
WEIGHTS:			
O.E.W.			
A.O.E.W.			
O.E.W.+A.O.E.W. ~ LB	326140	337760	365100
RANGE ~ N.MI.	3752	3629	3091
TAXI FUEL ~ LB.	4983	4872	5123
TAKEOFF FUEL ~ LB.	3195	2966	2820
SUBSONIC CLIMB: (TO M=0.85)			
FUEL ~ LB.	17601	15164	13,979
DISTANCE ~ N.MI.	24.4	21.5	17.3
SUPERSONIC CLIMB:			
FUEL ~ LB.	66852	72780	119,740
DISTANCE ~ N.MI.	407	519	1145.
CRUISE			
$C_{D_{PROD}}$ @ M=2.7	3.5	4.4	6.4
(N.MI./LB) INITIAL	.01258	.01271	.01331
WT= 580000 LB: ALTITUDE ~ FT.	68217	67473	67,767
(L/D) MAX	7.855	7.825	7.721
(L/D) CRUISE	7.837	7.822	7.717
Fn/δ	33.484	32.384	33.285
TSFC	1.4903	1.4812	1.4965
RF	8158	8188	7997
FUEL ~ LB	205,606	191,135	115510
DISTANCE ~ N.MI.	3074	2848	1695
(N.MI./LB) FINAL	.01797	.01763	.01623
DESCENT			
FUEL ~ LB.	3739	4005	4650
DISTANCE ~ N.MI.	247	242	234
ILS FUEL ~ LB.	1606	1541	1859
RESERVE FUEL ~ LB	58976	57551	58914
6% MISSION FUEL ~ LB.	18161	17548	15821
MISSED APPROACH FUEL ~ LB			
ALTERNATE (260 N.MI.)			
FUEL ~ LB	20,458	19888	21220
AVG. CRUISE: RF	5339	5638	5655
L/D	13.41	13.29	12.78
TSFC	1.2971	1.2168	1.1669
WEIGHT ~ LB	421,996	433,130	463,500
HOLD			
MACH	.475	.475	.500
FUEL ~ LB.	20,357	20115	21874
L/D	14.32	14.08	13.88
TSFC	1.4537	1.3731	1.376
AVG. WT. ~ LB	401,586	413,130	441,966
I.L.S. APPROACH			

* SIZED TO HAVE 200 FPM R/C CAPABILITY @ 64000 FT.

A/P =
M.T.W. = 750,000 LB
TEMP = STD.

TABLE A.3

ENGINE / AIRFLOW	TF2 /1090	TF7 /940	TF10 /955
CRUISE BPR	0.5	1.0	1.5
CRUISE R_{PC}	5.0	5.0	5.0
CRUISE R_{FAN}	2.5	2.5	2.2
WEIGHTS:			
O.E.W.			
A.O.E.W.			
O.E.W.+A.O.E.W. ~ LB	351,750	327,730	326,650
RANGE ~ N.MI.	3518	3871	3776
TAXI FUEL ~ LB	4406	3741	3505
TAKEOFF FUEL ~ LB	2525	2400	2316
SUBSONIC CLIMB: (TO M=0.95)			
FUEL ~ LB	14005	15437	16535
DISTANCE ~ N.MI.	26.3	46.3	60.7
SUPERSONIC CLIMB:			
FUEL ~ LB	48613	57,442	58646
DISTANCE ~ N.MI.	183	220	202
CRUISE			
$C_{D\,POD}$ @ M=2.7 ~ COUNTS	4.4	3.3	3.5
(N.MI./LB) INITIAL	.01265	.01239	.01205
WT = 550,000 LB: ALTITUDE	65716	63020	63433
$(L/D)_{MAX}$	7.85	7.950	7.929
$(L/D)_{CRUISE}$	7.84	7.841	7.841
F_N/δ	29.702	26.135	26.661
TSFC	1.4372	1.4873	1.5349
RF	8448	8164	7911
FUEL ~ LB	206,178	225,977	226014
DISTANCE ~ N.MI.	3073	3370	3278
(N.MI./LB) FINAL	.01771	.01813	.01765
DESCENT			
FUEL ~ LB	4506	3863	3929
DISTANCE ~ N.MI.	236	235	235
ILS FUEL ~ LB	1319	1029	966
RESERVE FUEL ~ LB	54450	50,129	49141
6% MISSION ~ LB	18697	18,591	18713
MISSED APPROACH FUEL ~ LB			
ALTERNATE (260 N.MI.)			
FUEL ~ LB	18697	15980	15719
AVG. CRUISE: RF	6164	6742	6820
L/D	13.24	13.68	13.65
TSFC	1.1091	1.0472	1.0333
WEIGHT ~ LB	445,253	416,093	413,996
HOLD			
MACH	.500	.475	.475
FUEL ~ LB	18860	15,558	14708
L/D	14.37	14.35	14.35
TSFC	1.2728	1.1171	1.0608
AVG. WT. ~ LB	426,474	400,324	398,782
ILS APPROACH			

A/P =
M.T.W. = 750,000 LB
TEMP = STD.

TABLE A.4

ENGINE / AIRFLOW	TF 25 / 930	TF 7 / 940	TF 43 / 960
CRUISE BPR	1.0	1.0	1.0
~~CRUISE R_c~~	~~4.0~~	~~5.0~~	~~6.0~~
~~CRUISE R_{FAN}~~	~~2.5~~	~~2.5~~	~~2.5~~
WEIGHTS:			
O.E.W.			
AO.E.W.			
O.E.W. + AO.E.W. ~ LB	325,600	327,730	331,870
RANGE ~ N.MI.	3859	3871	3704
TAXI FUEL ~ LB	4015	3741	3613
TAKEOFF FUEL ~ LB	2600	2400	2276
SUBSONIC CLIMB (TO M = 0.[illegible])			
FUEL ~ LB	17,445	15,437	14,[illegible]15
DISTANCE ~ N.MI.	52.3	46.3	43.8
SUPERSONIC CLIMB:			
FUEL ~ LB	57236	57442	59,252
DISTANCE ~ N.MI.	201	220	239
CRUISE			
C_D POD @ M = 2.7 ~ COUNTS	4.0	3.3	5.6
(N.MI./LB) INITIAL	.01260	.01239	.01194
WT = 550,000 LB: ALTITUDE ~ FT.	64192	63020	62786
$(L/D)_{MAX}$	7.900	7.950	7.697
$(L/D)_{CRUISE}$	7.845	7.841	7.841
F_N/q	27.599	26.135	26.305
TSFC	1.4684	1.4873	1.5115
RF	8274	8164	7886
FUEL ~ LB	222,770	225,937	222,097
DISTANCE ~ N.MI.	3370	3370	3191
(N.MI./LB) FINAL	.01837	.01813	.01739
DESCENT			
FUEL ~ LB	3836	3863	3867
DISTANCE ~ N.MI.	236	235	230
ILS FUEL ~ LB	1113	1029	1008
RESERVE FUEL ~ LB	53070	50,129	49,173
6% MISSION FUEL ~ LB	18542	18,591	18,401
MISSED APPROACH			
ALTERNATE (260 N.MI.)			
FUEL ~ LB	17716	15980	15578
AVG. CRUISE: RF	6078	6742	6977
L/D	13.55	13.68	13.36
TSFC	1.151	1.0472	0.9882
WEIGHT ~ LB	415,888	416,093	419633
HOLD			
MACH	.475	.475	.475
FUEL ~ LB	16,812	15,558	15,194
L/D	14.28	14.35	14.03
TSFC	1.2061	1.1171	1.0561
AVG. WT. ~ LB	398,624	400,324	404,247
ILS. APPROACH			

D6A11786-5

A/P =
M.T.W. = 750,000 LB
TEMP = STD

TABLE A.5

ENGINE /AIRFLOW	TF 6 /1065	TF 7 /940	TF 8 /1000
CRUISE BPR	1.0	1.0	1.0
CRUISE R_{∞}	5.0	5.0	5.0
CRUISE R_{FAN}	2.0	2.5	3.0
WEIGHTS			
O.E.W.			
A.O.E.W.			
O.E.W + A.O.E.W. ~ LB	342730	327730	332160
RANGE ~ N.MI.	3541	3871	3790
TAXI FUEL ~ LB.	3591	3741	3951
TAKEOFF FUEL ~ LB.	2382	2400	2387
SUBSONIC CLIMB: (TO M=0.95)			
FUEL ~ LB.	14699	15437	15280
DISTANCE ~ N.MI.	36.9	46.3	44.6
SUPERSONIC CLIMB:			
FUEL ~ LB	52940	57442	53091
DISTANCE ~ N.MI.	174	220	192
CRUISE			
C_D POD @ M=2.7 ~ COUNTS	5.1	3.3	3.9
(N.MI/LB) INITIAL	.01224	.01239	.01234
WT. = 570,000 LB: ALTITUDE ~ FT.	64596	63020	63356
WT. = 570,000 LB: (L/D) MAX	7.836	7.950	7.913
WT. = 570,000 LB: (L/D) CRUISE	7.792	7.841	7.818
WT. = 570,000 LB: W/δ	28.330	26.135	26.629
WT. = 570,000 LB: TSFC	1.4873	1.4873	1.4804
WT. = 570,000 LB: RF	8113	8164	8178
FUEL ~ LB.	213,286	225,937	224280
DISTANCE ~ N.MI.	3097	3370	3321
(N.MI./LB) FINAL	.01740	.01813	.01793
DESCENT			
FUEL ~ LB	4346	3863	4080
DISTANCE ~ N.MI.	233	235	233
ILS FUEL ~ LB.	1157	1029	1110
RESERVE FUEL ~ LB	52190	50,129	51325
6% MISSION FUEL ~ LB.	17568	18,591	18251
MISSED APPROACH			
ALTERNATE (260 N.MI.)			
FUEL ~ LB	17573	15,980	16514
AVG. CRUISE: RF	6393	6742	6618
AVG. CRUISE: L/D	13.29	13.68	13.58
AVG. CRUISE: TSFC	1.0729	1.0472	1.0595
AVG. CRUISE: WEIGHT ~ LB	433,671	416,093	421,986
HOLD			
MACH	.475	.475	.475
FUEL ~ LB	17049	15,558	16561
L/D	14.01	14.35	14.23
TSFC	1.1491	1.1171	1.1695
AVG. WT. ~ LB.	416,360	400,324	405,448
ILS APPROACH			

APPENDIX 2

Approximation to G. E. Turbofan

In a meeting with The Boeing Company on alternate cycles, the General Electric Co. discussed a mixed burning turbofan that they were evaluating. From its family of parametric engines, Boeing selected a duct burning turbofan with cruise BPR = .7, cruise R_p = 4.7 and cruise R_{Fan} = 2.0 (TFGE3) that more closely resembled the turbofan cycle that G.E. was evaluating. This turbofan cycle was compared against other Boeing parametric turbofans with similar engine parameters. The results, shown in Figure 18, show that to meet 118.5 airport noise and 108 EPNdb community noise, the optimum turbofan selected in this study with BPR = 1.0, R_p = 5.0, and R_{Fan} = 2.5 (TF7) is superior to the simulated G.E. turbofan.

PARAMETRIC ENGINE STUDY

MTW = 750,000 LB
P/L = 298 PASS.
STD. DAY, M = 2.7
CUTBACK THRUST AT COMMUNITY FOR R/C = 500 FPM
AIRPORT NOISE AT 1500 FT FROM RUNWAY ℄

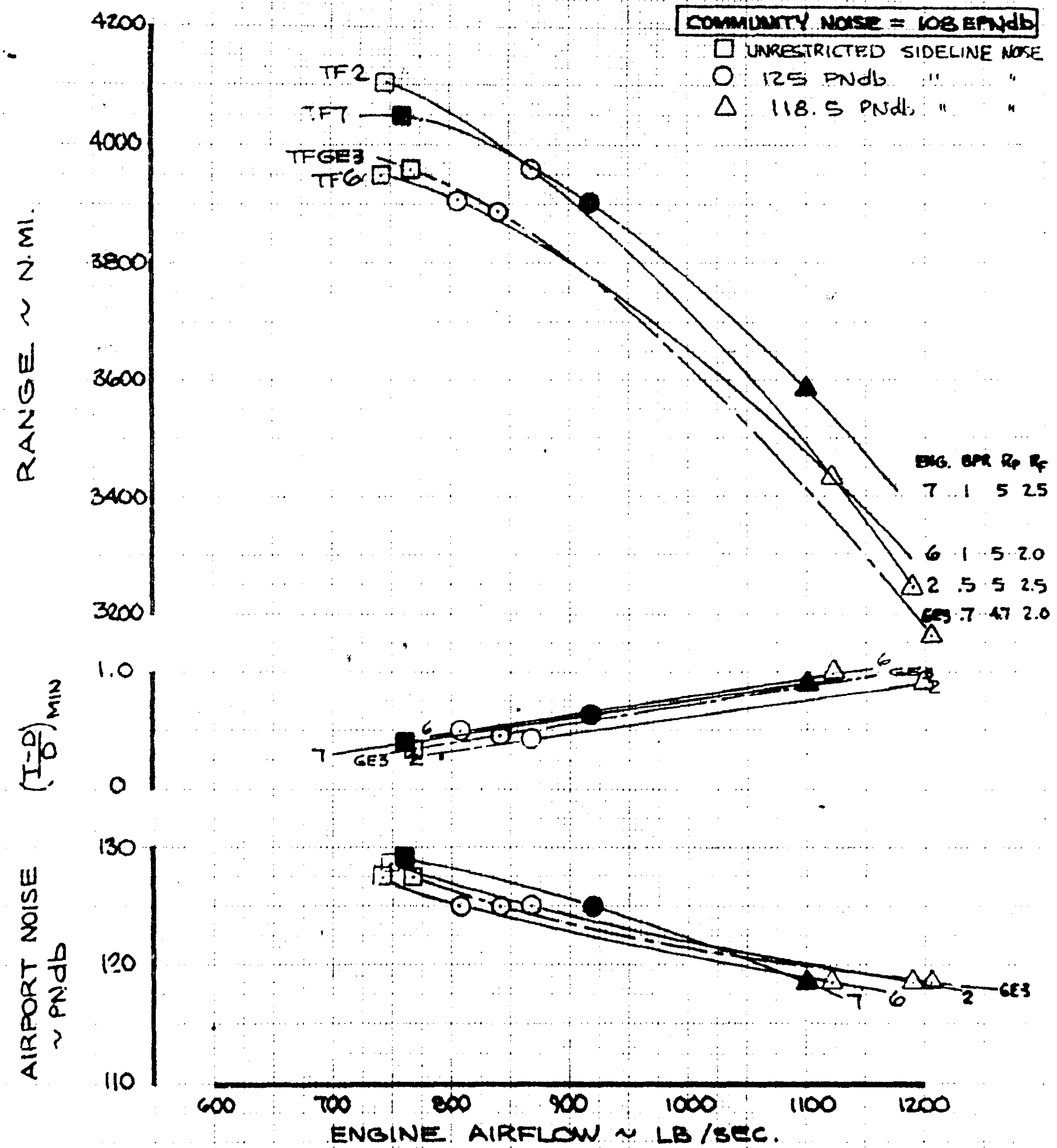


FIG. 18

CALC	AM	4/6/70	REVISED	DATE	APPROXIMATION TO GE TURBOFAN ENGINE, RANGE vs. AIRFLOW	D6A11786-5
CHECK						
APR						
APR					THE BOEING COMPANY	PAGE 53

APPENDIX 3

HIGH BYPASS RATIO, LOW FAN RATIO AFTERBURNING TURBOFANS

This appendix presents the results of the "first-cut" high BPR, low R_{Fan} afterburning turbofan evaluation. Figure 18 shows supersonic range performance and climb thrust margin for turbofans with cruise BPR = 2.0 and 2.5 with cruise R_p = 4.0, and for turbofans with cruise BPR = 2.5 and 3.0 with cruise R_p = 5.0. The cruise R_{Fan} for these four engines is about 1.5. These data show that decreasing BPR at a constant R_p increases range and that increasing R_p at constant BPR increases range. For comparison purposes, turbofan TF7 with cruise BPR = 1.0, R_p = 5.0, and R_{Fan} = 2.5 is also shown. Figure 19 shows the effect of subsonic legs on mission range for the four "first-cut" turbofans. These data show that subsonic cruise performance improves by increasing cruise R_p from 4.0 to 5.0 and by decreasing cruise BPR.

Parametric range trends showing the effect of cruise BPR and cruise R_p for the ductburning turbofans are shown in Figure 20. Figure 21 shows the incremental effect of cruise BPR and R_p on the climb, cruise, and reserve portions of the mission range. Figure 22 shows the incremental effects of cruise BPR and R_p on mission range because of weight and pod drag changes. Detailed mission tabulations of the four "first-cut" afterburning turbofans are shown in Table A.6.

PARAMETRIC ENGINE STUDY

PRODUCTION AIRPLANE (298 PASS)
MTW = 750,000 LB

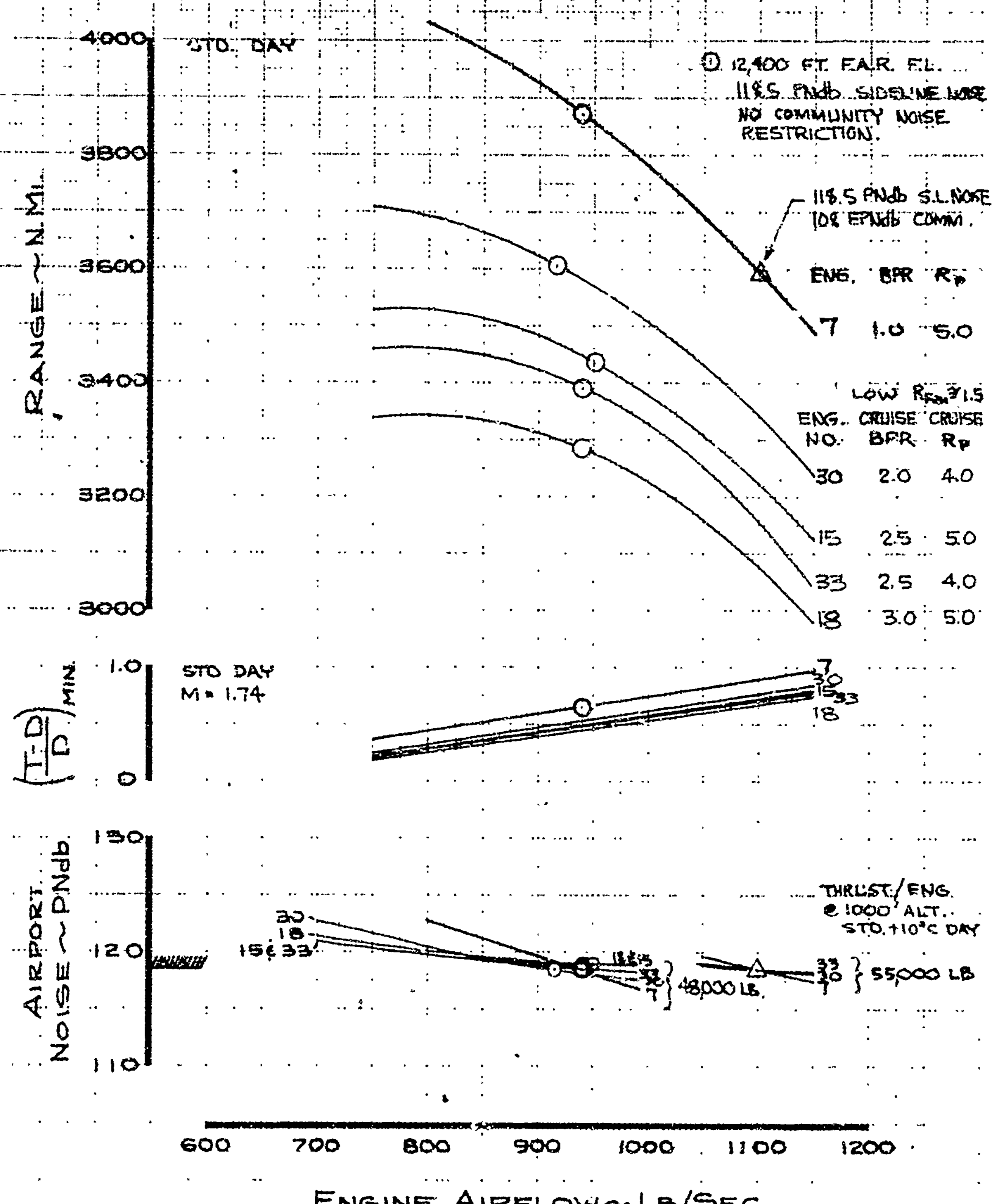


FIG. 19

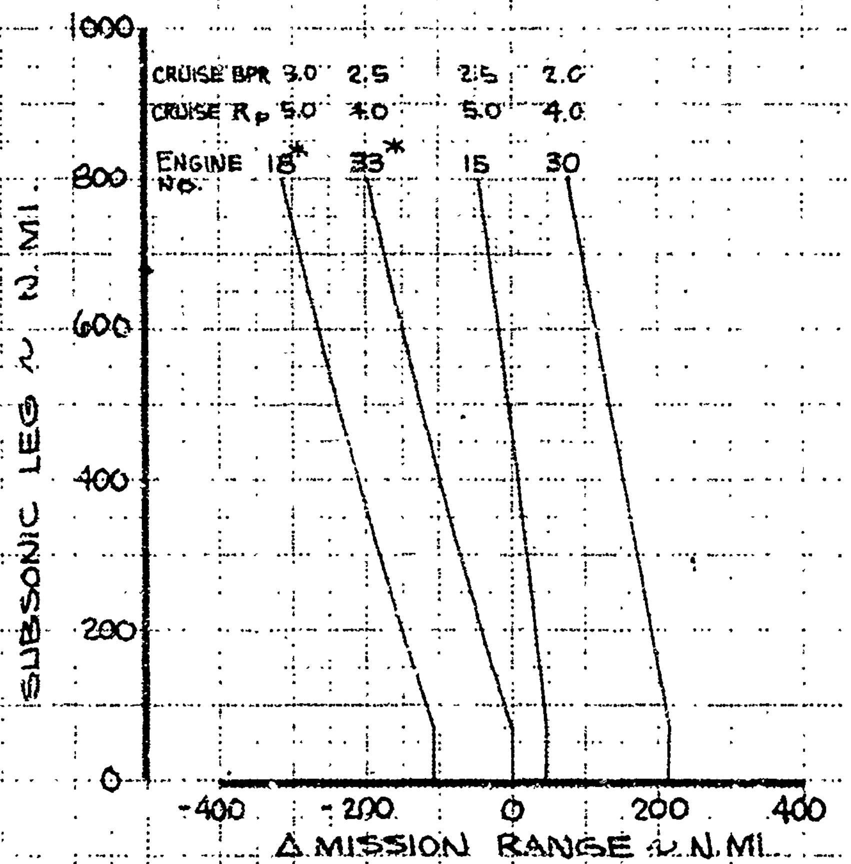
CALC	AM	1/21/70	REVISED	DATE	TURBOFAN ENGINE COMPARISON, EFFECT OF CRUISE BPR AND CRUISE R_p ON RANGE	D6A11786-5
CHECK			AM	1/26/70		
APR						
APR					THE BOEING COMPANY	PAGE 55

PARAMETRIC ENGINE STUDY

EFFECT OF SUBSONIC LEGS

MTW = 750000 LB
STD DAY
SUPERSONIC CRUISE M = 2.7
SUBSONIC CRUISE M = 0.9

AIRPORT NOISE = 118.5 PNdb
T.O. F.L = 12,400 FT.



* SUBSONIC LEG CRUISE ALTITUDE IS PLACARD LIMITED AT 27,000 FT. (I.E. BCA AT M = .9 IS BELOW 27,000 FT.)

FIG. 20

CALC	MURDSS	1/21/70	REVISED	DATE	TURBOFAN ENGINE COMPARISON, EFFECT OF SUBSONIC LEGS ON MISSION RANGE	D6A11786-5
CHECK			AM	1/26/70		
APR						
APR						
					THE BOEING COMPANY	PAGE 56

PARAMETRIC RANGE TRENDS

ENGINES SIZED FOR AIRPORT NOISE = 116.5 PNdB AT F_N = 48,000 LB / ENGINE

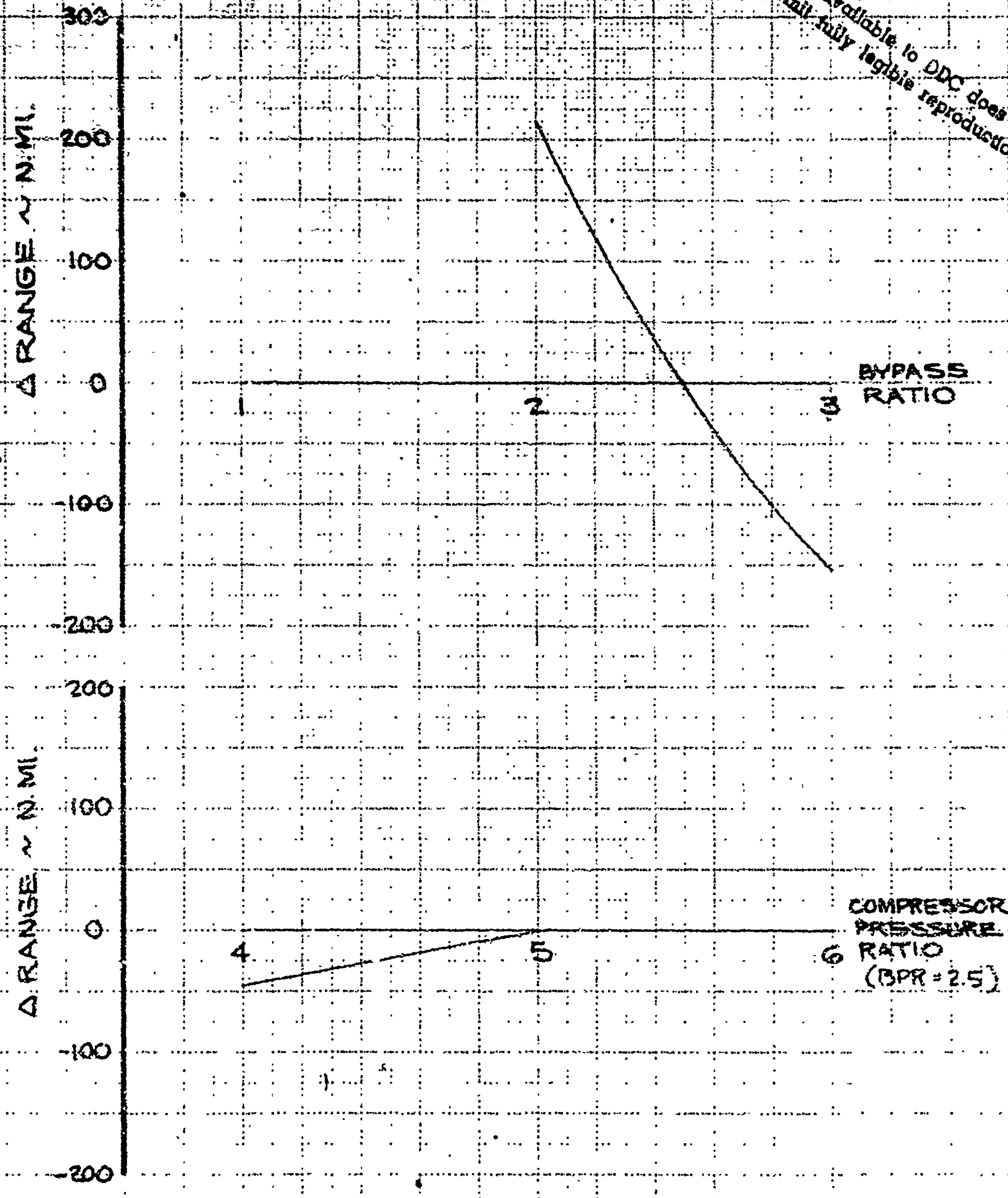


FIG 21

CALC	MORUSS	1/23/70	REVISED	DATE	TURBOFAN, PARAMETRIC RANGE TRENDS	D6A11786-5
CHECK			AM	1/26/70	EFFECT OF CRUISE BPR & CRUISE Rp ON NET RANGE	
APR						
APR					THE BOEING COMPANY	PAGE 57

PARAMETRIC ENGINE TRENDS
ENGINE PERFORMANCE EFFECTS

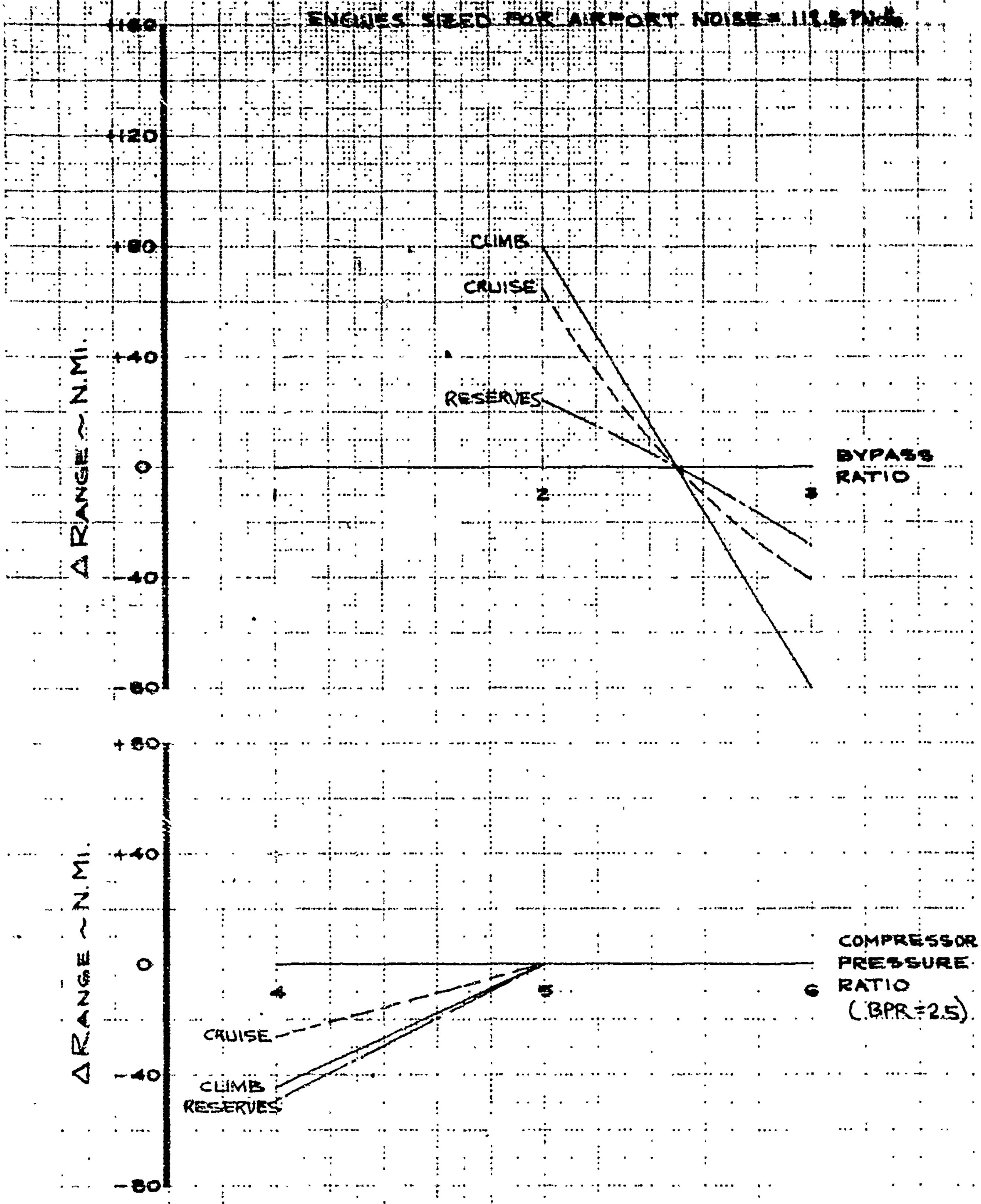


FIG. 22

CALC	MORLISS	1/22/70	REVISED	DATE	TURBOFAN ENGINE COMPARISON EFFECT OF CRUISE BPR AND CRUISE R_P ON RANGE DUE TO CLIMB ~~CRUISE AND RESERVES~~	D6A11786-5
CHECK						
APR						
APR					THE BOEING COMPANY	PAGE 58

PARAMETRIC ENGINE TRENDS
WEIGHT AND DRAG EFFECTS

ENGINES SIZED FOR AIRPORT NOISE = 112.5 PNdB

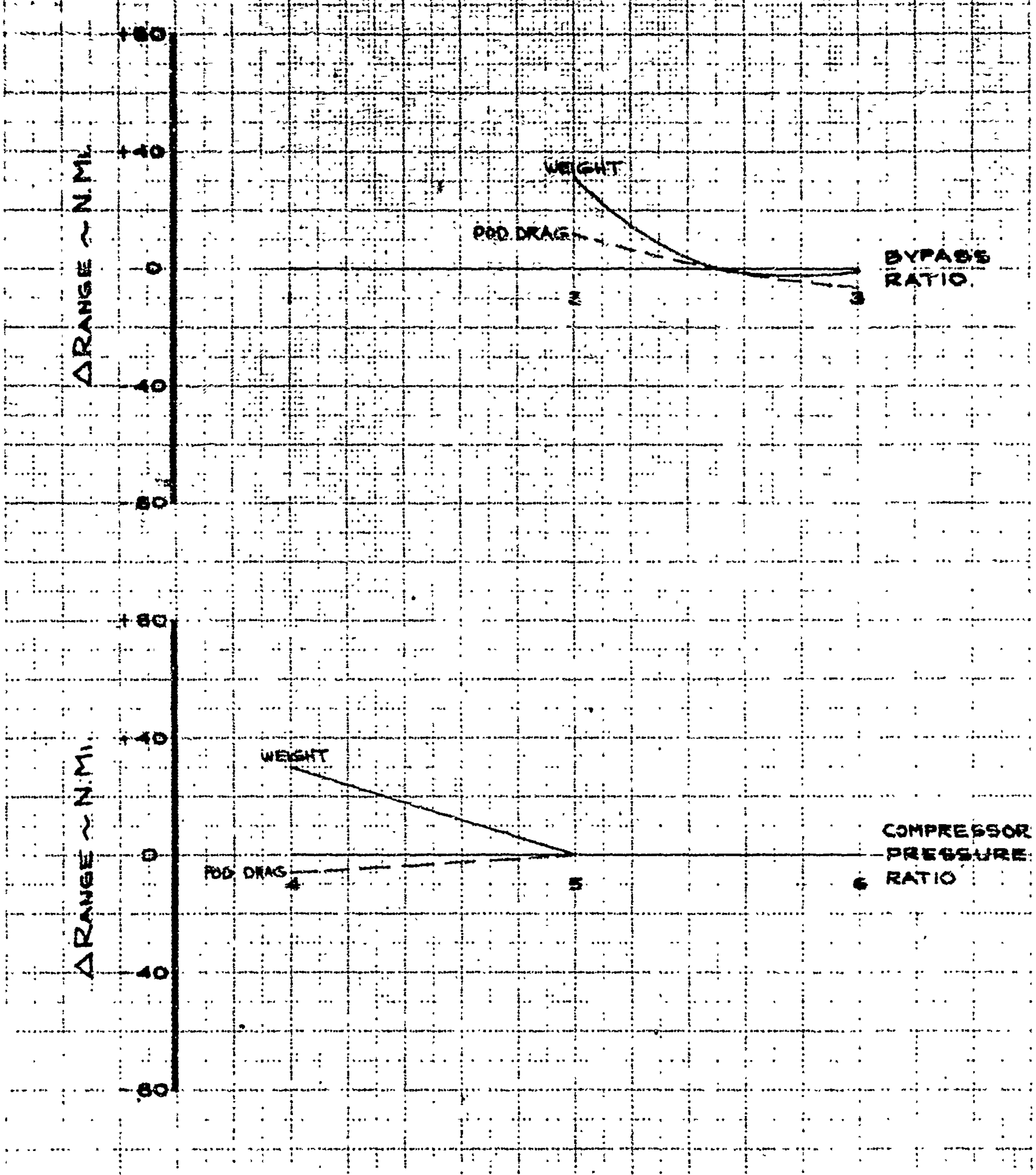


FIG. 23

CALC	MORUSS	1/22/70	REVISED	DATE	TURBOFAN ENGINE COMPARISON, EFFECT OF CRUISE BPR AND CRUISE R_p ON RANGE DUE TO ~~WEIGHT AND POD DRAG~~	D6A11786-5
CHECK						
APR						
APR					THE BOEING COMPANY	PAGE 59

A/P = PROD A/P (298 PASS)
MTW = 750,000 LB
TEMP = STD. DAY

TABLE A.6

ENGINE - AIRFLOW	33-940	15-950	18-940	30-916
CRUISE BPR	2.5	2.5	3.0	2.0
CRUISE R_P	4.0	5.0	5.0	4.0
WEIGHTS				
OEW	322760	324530	324600	320940
ΔOEW				
OEW+ΔOEW				
RANGE ~ N.MI.	3390	3435	3282	3604
TAXI FUEL ~ LB	3398	3182	2825	3434
TAKEOFF FUEL ~ LB	4877	4582	5109	4324
SUBSONIC CLIMB (TO M=0.95)				
FUEL ~ LB	22916	20794	23613	20415
DISTANCE ~ N.MI.	60.6	54.5	66.4	52
SUPERSONIC CLIMB				
FUEL	71590	69601	75127	67221
DISTANCE	201.7	204.1	209.1	208.4
CRUISE				
C_D POD & MIZT, COUNTS	4.7	4.5	4.7	4.3
(N.MI./LB) INITIAL	.01195	.01174	.01170	.01206
WT= 550,000 LB: ALTITUDE ~ FT	64503	63404	63547	63278
(L/D)MAX				
(L/D)CRUISE	7.803	7.776	7.775	7.795
FN/q	28.163	26.848	27.040	26.595
TSFC	1.5931	1.6017	1.6240	1.5569
RF	7585	7518	7414	7754
FUEL ~ LB	204,699	210,625	200265	215702
DISTANCE ~ N.MI.	2895.5	2945.7	2775.6	3111.5
(NMI/LB) FINAL	.01695	.01683	.01654	.01744
DESCENT				
FUEL ~ LB	3818	3837	3797	3711
DISTANCE ~ N.MI.	232.5	231	231.4	231.7
ILS FUEL ~ LB	1129	924	1023	945
RESERVE FUEL ~ LB.	52512	49620	51340	51010
6% MISSION FUEL ~ LB	18746	18813	18706	18945
MISSED APPROACH				
ALTERNATE (260 N.MI.)				
FUEL ~ LB	19474	17369	19595	17575
AVG. CRUISE: RF	5489	6158	5457	6029
L/D	12.89	13.22	12.41	13.38
TSFC	1.2199	1.1083	1.1909	1.1455
WEIGHT ~ LB	411539	411257	412041	408828
HOLD				
M	.450	.475	.450	.475
FUEL	14292	13438	13039	14489
L/D	13.69	14.15	13.68	14.20
TSFC	.9931	.9619	.9025	1.0494
AVG. WT.	394656	395854	395725	392796
ILS APPROACH				

APPENDIX 4.0

Pod Drag Comparisons

This appendix presents the formulae that were used to calculate pod drags for this parametric study. In addition, pod drag comparisons of the best engine of each cycle are shown in Table A7. Pod sketches of these engines are shown in Figure 24.

The pod drag formulae for cruise conditions at M = 2.7, altitude = 60,000 ft and $S_{Ref.} = 7700\ ft^2$ are:

- o Afterburning Turbojet (Base Pod PPID - 108)

$$C_D \times 10^4 = .0070\, A_{WET} - .00152\left(D^2_{max} - D^2_{inlet}\right) + .000162\, \alpha^2 \left(D^2_{max} - D^2_{exit}\right) + 1.0$$

- o Dry [illegible]et (Base Pod PPID-112)

$$C_D \times 10^{\text{[illegible]}}\ \text{[illegible]}705\, A_{WET} - .001505\left(D^2_{max} - D^2_{inlet}\right) + .0001012\, \alpha^2 \left(D^2_{max} - D^2_{exit}\right) + 1.0$$

- o Duct Burning Turbofan (Base Po[illegible] PPID-105, Rev. A)

$$C_D \times 10^4 = .00711\, A_{WET} - .001285\left(D^2_{max} - D^2_{inlet}\right) + .000153\, \alpha^2 \left(D^2_{max} - D^2_{exit}\right) + 1.0$$

Where

A_{wet} = External wetted area of one pod (ft^2)

D = Diameter (inches)

α = Boattail angle (degrees)

AD 1586 D

TABLE A7

DRAG COMPARISON

ENGINES SELECTED FOR:

118.5 PNdb AIRPORT NOISE

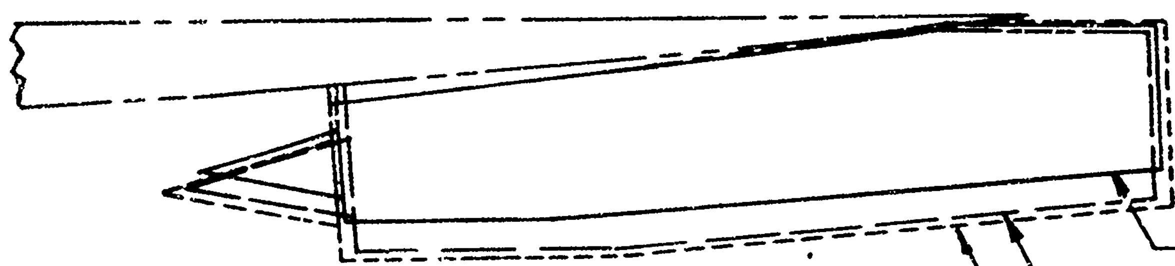
108 EPNdb COMMUNITY NOISE

ENGINE TYPE	AIRFLOW ~LB./SEC.	MAX. DIAMETER ~IN.	BOATAIL ANGLE ~DEG	Δ DRAG [1] ~COUNTS
AFTERBURNING TURBOJET WITH SUPPRESSOR	710	99.2	3.0	+1.1
DRY TURBOJET	920	101	3.25	+1.9
TURBOFAN	1100	107	2.50	+2.0

[1] RELATIVE TO UNSUPPRESSED AFTERBURNING TURBOJET AT 633 LB./SEC.

FIGURE 24

PARAMETRIC ENGINE STUDY



ENGINE TYPE	POD DRAWING	AIRFLOW ~LB/SEC	MAX. DIAMETER ~ INCHES	Δ GEAR LENGTH REQUIRED* ~INCHES
AFTERBURNING TURBOJET	PPID-108	633 ▷	85.0	-3.9
DRY TURBOJET	PPID-113	920	101.0	+8.2
TURBOFAN	PPID-105A	1100	107.0	+17.7

* LENGTH TO BE ADDED TO PPD LANDING GEAR TO MAINTAIN 14° LANDING ROTATION CLEARANCE.

▷ UNSUPPRESSED, F.L. < 10,500 FT.

APPENDIX 5.0

Engine Parameter Comparison

This appendix presents a tabulation of cruise and sea level static values of BPR, R_p and R_{Far} for the engines evaluated in this study.

AD 1546 C

TABLE A8

ENGINE TYPE	ENGINE NUMBER	CRUISE M = 2.7, 60,000 ft.			SEA LEVEL STATIC		
		Bypass Ratio BPR	Compressor Pressure Ratio Rp	Fan Pressure Ratio R_{Fan}	Bypass Ratio BPR	Compressor Pressure Ratio Rp	Fan Pressure Ratio R_{Fan}
Afterburning Turbojet	TJ-2A	-	5	-	-	12.66	-
Dry Turbojet	TJ-1D	-	4.0	-	-	9.24	-
	TJ-2D	-	5.0	-	-	12.66	-
	TJ-3D	-	6.0	-	-	16.29	-
Ductburning Turbofan	TF-2	0.5	5.0	2.5	.487	12.75	4.96
	TF-6	1.0	5.0	2.0	.879	13.21	3.66
	TF-7	1.0	5.0	2.5	.974	12.81	4.99
	TF-8	1.0	5.0	3.0	1.055	12.28	6.26
	TF-10	1.5	5.0	2.2	1.381	13.16	4.24
	TF-25	1.0	4.0	2.5	1.062	8.97	4.71
	TF-43	1.0	6.0	2.5	.918	16.85	5.18